PLOWPAN INVESTIGATIONS at the GREAT PLAINS FIELD STATIONS

Woodward, Okla., and Mandan, N. Dak.

Agricultural Research Service
United States Department of Agriculture
in cooperation with
the Oklahoma Agricultural Experiment Station
Production Research Report No. 40

CONTENTS

WASHINGTON, D.C. Issued October 1960

PLOWPAN INVESTIGATIONS at the GREAT PLAINS FIELD STATIONS

Woodward, Okla., and Mandan, N. Dak.[1]

By Lowell F. Locke, Harold V. Eck, Bobby A. Stewart, and Howard J. Haas, *soil scientists, Soil and Water Conservation Research Division, Agricultural Research Service, from Woodward, Okla.; Bushland, Tex.; Fort Collins, Colo.; and Mandan, N. Dak., respectively.*

One of the many soil-management problems encountered by agricultural workers is the change that occurs in soil profiles as a result of tillage operations. Such operations frequently result in the formation of a layer immediately below plowing depth which has properties that deviate from those of the soil above and below it. This differential layer has been referred to as plowpan or tillagepan, and since it usually is higher in density than adjacent layers, it is presumed to result from differential compaction during tillage operations. Extensive observations were made on such layers at Woodward, Okla., and at Mandan, N. Dak. A summary of these observations, including data relating to the physical nature of the layer and its effect on certain physical and biological processes, is presented in this publication. The material is divided into the following five sections: Root Impedance; Infiltration Studies; Penetration, Bulk-Density, and Soil-Moisture Studies; Organic Matter and Mechanical-Analysis Studies; and Greenhouse Plant-Growth Studies. Data from Woodward are included in all five sections, whereas those from Mandan are limited to the third section.

DESCRIPTION OF SOILS

The soil at Woodward is classified as Pratt fine sandy loam. The Pratt series occurs on undulating upland plains of west-central and northwestern Oklahoma and southern Kansas in the Reddish Chestnut, Reddish Prairie, Chestnut, and Chernozem soil zones. The Pratt soils, as they occur naturally, are freely drained, both from the surface and internally. A detailed description of the soil at Woodward is given in appendix I.

On the experimental area at the Woodward station, the sod was broken in 1914. From that time through 1948, five crops—broomcorn, corn, kafir, milo, and sorgo—were grown each year according to the continuous-cropping moisture-conservation experimental plan of the former Division of Dry Land Agriculture. Since 1949 the field has been uniformly cropped with grain sorghum, after shallow one-way plowing. Much of the work reported in this publication was done on soil from two plots, the MC kafir shallow-

[1] These investigations were carried out at the Southern Great Plains Field Station, Woodward, Okla., and at the Northern Great Plains Field Station, Mandan, N. Dak.

plowed plot A and the deep-plowed plot B in field A. However, certain studies were made on other plots and many other observations were also made on the station and in the general area.

The soil at Mandan is classified as Cheyenne fine sandy loam. It occurs on a high terrace, is nearly level, and is well drained, both from the surface and internally. A detailed description of the soil at Mandan is given in appendix II. The soils on which the studies were conducted had been cropped to 3-year rotations of corn, wheat, and oats for more than 30 years.

ROOT IMPEDANCE

Some of the effects of the plowpan that developed on the experimental field at the Woodward station are shown in figures 1 through 5. Figure 1 illustrates differences in root development of Wheatland milo plants grown in soils with and without plowpans.

Figure 2, *A* shows a Wheatland milo plant that was removed from the field in a core of plowpan soil and figure 2, *B*, cleavage planes of soil and lack of root development in this core. Root development of a Wheatland milo plant above the plowpan in a dry season is shown in figure 3. Similar observations have been made on wheat root systems in this soil.

When row crops are planted while the soil is wet and rain does not occur for some time, plant roots are often confined to the planter shoe furrow for weeks or even months (fig. 4). Apparently the roots are unable to penetrate the dry glazed layer.

Figure 1.—Roots of Wheatland milo plants growing in soil: *A*, With a well-developed plowpan; *B*, without a pan. Woodward, Okla., 1955.

FIGURE 2.—*A*, Wheatland milo plant growing in plowpan soil; note the small head and poor growth; *B*, cleavage planes of soil and poor root development of the plant in the same core. Woodward, Okla., 1955.

FIGURE 3.—Root of a Wheatland milo plant in the dry season of 1955 at Woodward, Okla. Note the poor root development.

FIGURE 4.—Kafir plant showing roots confined to the planter shoe furrow. Woodward, Okla., 1936.

Figure 5, *A*, shows a core of soil containing roots of a milo plant; figure 5, *B*, the same core after part of the soil had been washed away; and figure 5, *C*, the roots that had been contained in the soil. The initial soil core was 6 inches in diameter and 15 inches long. Water was sprayed over the core as uniformly as possible. As shown in figure 5, *B*, there was a considerable difference in rapidity of erosion of the various soil layers. The plowpan was most resistant and therefore was the last to be washed away. The roots in and below the plowpan zone were a remarkably small part of the total roots found in the core.

Plowpan is responsible for decreased yields and increased runoff and soil erosion losses. It also reduces infiltration and hinders root penetration.

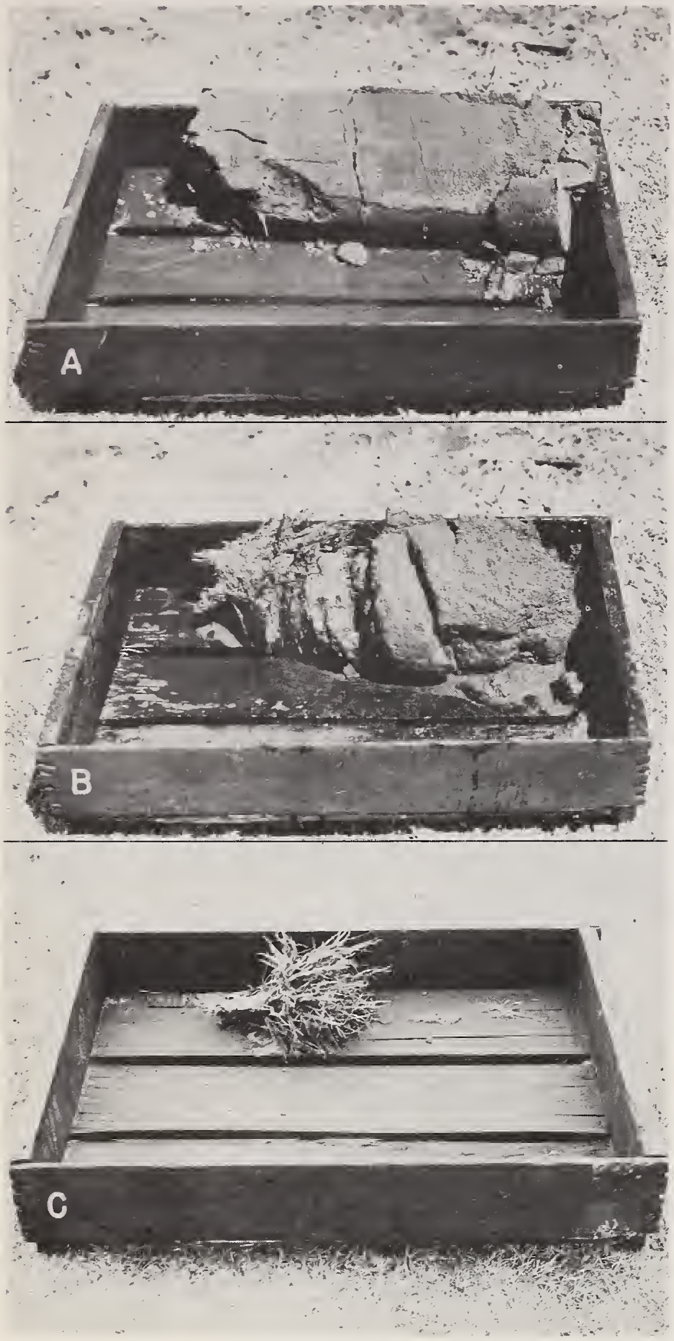

FIGURE 5.—Wheatland milo plant stubble and soil removed from sampling can: *A*, Ready for soil to be washed from roots; *B*, after partial removal of the soil by washing; note blocking of roots by hardpan; *C*, soil completely washed from stubble and roots; note distribution of roots. Woodward, Okla., 1956.

FIGURE 6.—Double-ring infiltrometer used in field tests at Woodward, Okla.

INFILTRATION STUDIES

Field Studies

Field studies on the infiltration of water through plowpan were conducted by Locke and Bull in 1948, as reported in Locke and Mathews (*7*).[2] They found that water from an infiltrometer penetrated the plowpan layer at the rate of about 0.2 inch per hour. However, when this layer was removed and the infiltrometer was set on the soil immediately below it, the rate increased to 9 inches per hour. These findings were confirmed by Olmstead (*in 7*) in 3-inch undisturbed cores from different plots in the same field.

In 1955 concentric ring recording infiltrometers (figure 6) were used in a study of infiltration rates in the field at Woodward. When the infiltrometer rings were set near the surface of the soil, an undetermined but considerable amount of water moved laterally through the soil. This, of course, invalidated any readings taken in this position. When the soil was carefully excavated down to the plowpan and the concentric rings were placed directly on the surface of the plowpan, the infiltration rate was measured at 0.2 inch per hour. In general, these studies showed, as did those of Locke and Bull, that the infiltration rate in the plowpan is much slower than that in the soil beneath it.

In the fall of 1956 the surface soil was thoroughly dry and modifications of suggestions[3] for showing infiltration visually were tried. The final method used was to dig a pit large enough in which to use a camera. Tops and bottoms were removed from 46-ounce fruit-juice cans. These open-end cans were placed about 4 inches from the edge of the pit and pressed into the soil to a depth of 2 to 3 inches. The cans were filled with water and the progress of infiltration was photographed at intervals.

Vertical penetration of the water from the surface, as recorded photographically at intervals, was as follows:

Hours	*Inches*
1½	4⅜ (figure 7, *A*)
2½	4⅝
3½	5½
4	5⅞ (figure 7, *B*)
5	6⅛
6	6¾ (figure 7, *C*)
7	6⅞
7½	7⅝ (figure 7, *D*)

As had been suggested, the penetration was delayed by cracks in the soil and by changes in the soil layers. Instead of the water running down the cracks, moisture movement, both vertical and horizontal, was delayed where the cracks were not continuous to the surface.

Figure 7 illustrates the slow penetration of water into dry soil during the 7½-hour period.

Delay of moisture penetration by horizontal and by vertical cracks during 2 hours' movement of the wetting front is shown in figure 8.

Laboratory Studies

Laboratory determinations of percolation rate, pore space, mechanical analysis, moisture equivalent, and bulk density were made on undisturbed soil taken at three locations on each of two plots, MC kafir plot A and plot B. Plot A had been plowed to a depth of 5 inches and plot B to a depth of 8 inches during the period 1914–48. At each location 3-inch cores were taken—three in the 1- to 4-inch depth, three in the plowpan (5- to 8-inch depth on plot A and 7- to 10-inch depth on plot B), and two just above the plowpan (3- to 6-inch on plot A and 4- to 7-inch on plot B). Only two cores were taken below the plowpan—both in the 11- to 14-inch depth on plot B.

Percolation rate was measured under a ½-inch hydraulic head after the soil cores had been allowed to stand in approximately ¾ inch of water for 24 hours. Total pore space was measured by weighing the cores at saturation and at oven dryness and calculated by the following formula:

$$\frac{\text{Sat. wt.} - \text{dry wt.}}{\text{Volume of core}} \times 100 = \text{Percent total pore space}$$

Macro pore space was measured by weighing the cores at saturation and at one-third atmosphere

[2] Italic numbers in parentheses refer to Literature Cited, p. 32.

[3] Suggestions by Glen H. Cannell, formerly with the staff at Mandan, now with the Department of Irrigation and Soils, University of California, Riverside.

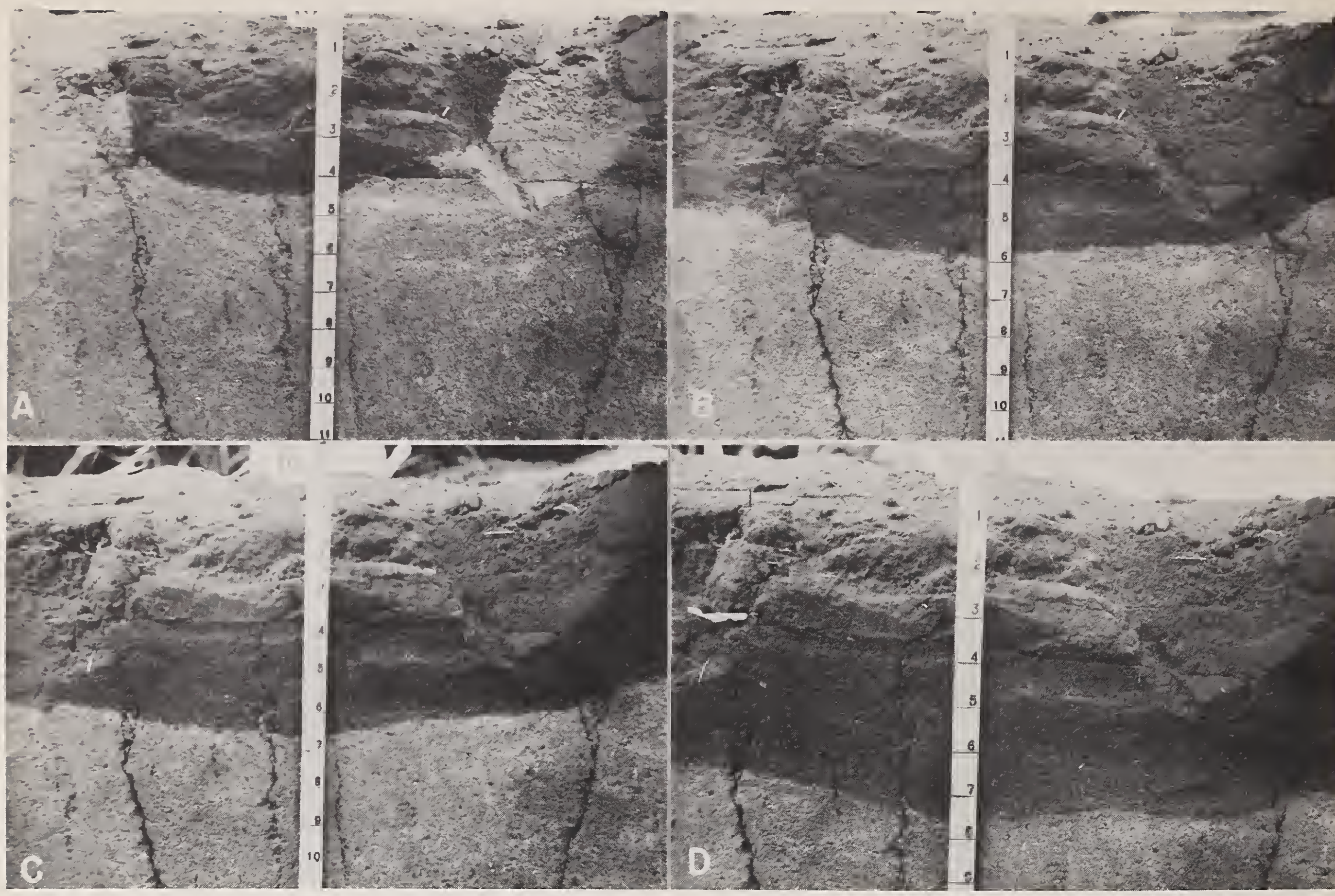

FIGURE 7.—Penetration of water from open-bottom can · *A*, About 4⅜ inches after about 1½ hours; *B*, 5⅞ inches after 4 hours; *C*, 6¾ inches after 6 hours; and *D*, 7¾ inches after 7½ hours. Woodward, Okla., 1956.

percentage and calculated by the following formula:

$$\frac{\text{Sat. wt.} - \text{wt. at } 1/3 \text{ atmos.}}{\text{Volume of core}} \times 100 = \text{Macro pore space}$$

Micro pore space was calculated by subtracting the macro pore space from the total pore space. Mechanical analysis was determined by the method of Bouyoucos (*1*) and moisture equivalent, by the centrifuge method described by Briggs and McLane (*2*).

Data on percolation rate in inches per hour; pore space, mechanical analysis, and moisture equivalent in percentages; and bulk density in grams per cc. are presented in table 1. Each measure was subjected to statistical analysis by the following analysis of variance:

Variant	*D.f.*
Total	23
Holes	2
Depths	2
Holes×depths (error)	4
Subsampling	15

The various determinations were compared within the plots and not between them. Data for the 11- to 14-inch depth were not included in the analysis of variance, since too few samples were taken. Coefficients of variation in table 1 are indicative of the uniformity of the data.

The high coefficients of variation, especially those for percolation rate and macro pore space, indicate that too few samples were taken to measure adequately some of the physical qualities of the soil. However, some differences were found and some conclusions may be drawn.

There were no significant changes with depth in percolation rate, moisture equivalent, and bulk density on either of the plots. Total and micro pore space did not change significantly with depth; however, macro pore space changed significantly with depth on the deep-plowed plot. The quantity in the 1- to 4-inch depth was significantly greater than that in the 7- to 10-inch depth; however, micro pore space in the 4- to 7-inch depth was intermediate between and not

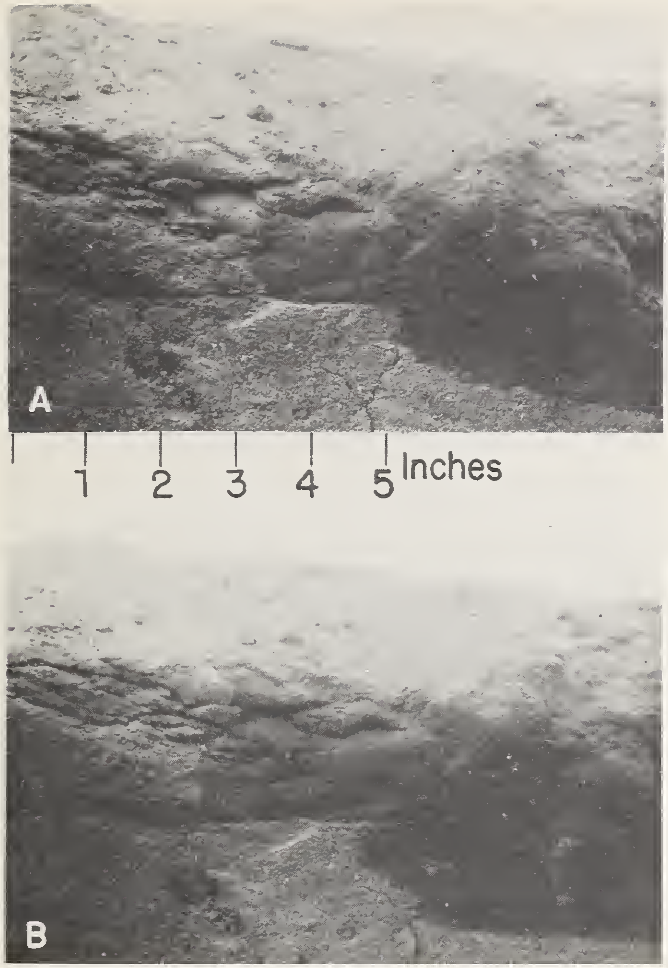

FIGURE 8.—Progress of wetting front during a 2-hour period in a soil with compacted zone. *B* was taken 2 hours after *A* during the course of water application. Note how water penetration is delayed by cracks in the soil.

different from that in the 1- to 4-inch and 7- to 10-inch depths.

Percentage composition of sand and silt did not change significantly with depth; however, percentage of clay increased with depth on both plots. On the shallow-plowed plot, the increase with depth was consistent, but on the deep-plowed plot the increase was much greater between the 1- to 4-inch and the 4- to 7-inch depths than between the 4- to 7-inch and the 7- to 10-inch depths.

Correlations between percolation rate and percentage clay were calculated on individual determinations for both plots. On the shallow-plowed plot A, the correlation coefficient (r) was −0.46, whereas on the deep-plowed plot B it was −0.33. Neither coefficient was high; however, that on the plot A was significant at the 5-percent level. Percentage clay was converted to grams of clay per core sample and the correlations were rerun. Coefficients were −0.40 for plot A and −0.59 for plot B. They were significant at the 5- and 1-percent levels, respectively. Though the correlations were not high, the percolation rate decreased as the clay content increased.

Data obtained from the two cores taken below the plowpan on plot B indicate that percolation rate is much higher and that bulk density is lower below the plowpan than in or above it. Clay and sand contents are higher and the silt content is lower below the plowpan than in or above it.

The relatively minor differences in the physical qualities of the soil measured in and above the plowpan indicate that there is little difference between the two layers of soil. These results are rather disappointing when visual differences and infiltration in the field are considered. However, the cores yielded soil samples in 3-inch sections, whereas the soil in the plowpan varied in thickness. The plowpan was probably adulterated with soil material from above or below, thereby affecting all the laboratory determinations, except percolation rate. It is apparent, also, that too few samples were taken to measure the percolation rate adequately. The data obtained do not explain the impenetrability of the plowpan when a probe is pushed into the soil nor its impenetrability to roots. There is an indication that the clay content changes with depth and that the percolation rate is inversely related to the clay content. The need for further studies on thinner sections of soil is apparent.

TABLE 1.—*Percolation rate, pore space, mechanical analysis, moisture equivalent, and bulk density of soil in 3-inch cores taken from kafir shallow-plowed plot A and kafir deep-plowed plot B. Woodward, Okla., 1955*

Plot and depth, inches	Percolation rate	Pore space			Mechanical analysis			Moisture equivalent	Bulk density
		Total	Macro	Micro	Sand	Silt	Clay		
Plot A:	*In./hr.*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*G./cc.*
1 to 4 [1]	0.63	35.67	7.36	28.30	75.8	17.3	6.9	6.46	1.63
3 to 6 [2]	.17	32.38	6.32	26.23	75.3	16.5	8.2	7.86	1.72
5 to 8 [1]	.20	34.26	6.64	27.63	70.2	19.4	10.5	9.62	1.67
Coefficients of variation (%)	139.7	10.6	26.5	8.5	5.8	15.0	20.7	23.4	14.3
Plot B:									
1 to 4 [1]	0.30	38.81	8.37	30.44	68.2	22.7	8.8	8.32	1.60
4 to 7 [2]	.15	33.37	5.31	28.07	67.7	22.8	9.8	9.18	1.70
7 to 10 [1]	.11	32.82	4.85	26.95	69.5	20.5	10.0	8.96	1.73
11 to 14 [3]	1.77	36.74	7.76	28.98	73.0	15.0	12.0	10.88	1.53
Coefficients of variation (%)	110.6	21.6	118.0	3.7	6.1	19.1	6.7	7.9	5.7

[1] Average of 9 determinations (3 subsamples at each of 3 locations on a plot).
[2] Average of 6 determinations (2 subsamples at each of 3 locations on a plot).
[3] Average of 2 determinations (2 subsamples at 1 location on a plot).

PENETRATION, BULK-DENSITY, AND SOIL-MOISTURE STUDIES

Studies at Mandan

Penetration studies were conducted at Mandan on a number of the rotation plots that had been in operation for more than 30 years. A soil penetrometer was used similar to one described by Shaw *et al.* (*8*). These studies disclosed that an induced plowpan was forming under plots that had been spring plowed, whereas there was little evidence of one forming under plots that had been fall plowed. The differences in plowpan formation were attributed to the differences in moisture content of the plots at the time of plowing. Generally, the soil is more moist in the spring than in the fall and thus is subject to greater compaction under spring plowing. The compact layer, however, apparently has not become sufficiently severe to influence yields as yet.

The finding of a plowpan warranted further study (1) to determine the relationship between soil penetrometer readings and bulk-density measurements, and between soil penetrometer readings and soil-moisture values; (2) to determine whether the effect of a single plowing operation on soil compaction could be detected by penetrometer and bulk-density measurements; and (3) to determine whether any changes occurred in the plowpan over winter or, (4) over summer.

Two 3-year triplicated rotations were selected for study. Both rotations consisted of a sequence of corn, wheat, and oats. However, all plots in rotation 2 were spring plowed and all in rotation 3 were fall plowed. Only the plots in wheat and oats were studied. Penetrometer readings, bulk-density measurements, and soil-moisture determinations were made before and after plowing in the spring and fall during two seasons. Each plot was one-tenth acre in area and five locations were sampled per plot. The cross section area of the point of the probe of the penetrometer was 1 square inch.

An attempt was made to eliminate moisture as a variable influencing the penetrometer readings by wetting the sampling locations 1½ to 2 days before the readings were to be made. One-gallon fruit-juice cans, with the ends removed, were set

on the soil surface and the inside edge of the can was sealed with dust. The cans were filled with water twice—a total of approximately 12 inches of water. However, even with this wetting, there was still considerable variability in soil-moisture values.

Bulk-density measurements were made by means of a sharp-edged tube 18 inches long and 1.34 inches in diameter. Twelve slots were cut in the tube at 1-inch intervals at right angles to the tube. The tube was forced into the soil by hand to a depth of 13 inches. After the tube was removed, a specially constructed knife was inserted in the upper slot at right angles to the tube and worked back and forth to cut the top inch of soil. With the knife remaining in the tube, the tube was tipped and the first inch of soil placed in a soil can. This procedure was followed for the remaining inches through the twelfth inch. The thirteenth inch was discarded. When compaction in the tube occurred, the samples were discarded and the location was resampled. Two borings were made at each location, and the two samples for each depth were composited, weighed, dried at 105° C., and reweighed. All data were recorded separately for each location in each plot.

Mechanical analysis showed little difference in texture between the 0- to 6-inch and 6- to 12-inch soil sections for a given plot. However, there was a difference in texture between plots.

To facilitate studying the relationship of penetrometer readings to soil-moisture and bulk-density measurements, the penetrometer values were grouped by 1-percent soil-moisture intervals and by 0.05-gram per cc. bulk-density intervals. This grouping was used regardless of depth. The effect of soil moisture on penetrometer readings was then determined in each bulk-density interval. In other words, the effect of bulk density was eliminated. Likewise, the effect of bulk density on penetrometer readings was determined within each soil-moisture interval and, in this instance, the effect of soil moisture was eliminated.

Regression equations and correlation coefficients showing the relationship between penetrometer readings and soil-moisture determinations for each bulk-density interval are presented in table 2. All correlation coefficients are low, but owing to the large number of samples involved, several tested significant at the 1-percent level. However, even the highest significant r value (−0.32) would indicate that only 10 percent of the variability of the penetrometer readings was due to moisture. At low bulk density, r values were positive in most instances but did not test significant with one exception. At bulk-density intervals of 1.31 to 1.35 and higher, all r values were negative and tested significant at the 1-percent level with one exception. Apparently moisture had no influence on penetrometer readings at low bulk density but became important at bulk densities greater than 1.30.

Table 2.—*Correlation and regression of penetrometer readings and soil moisture at various bulk-density intervals. Mandan, N. Dak.*

Bulk-density interval, g./cc.	Number of comparisons	Correlation [1] coefficient	Regression equation
Rotation 2—spring plowed:			
1.01 to 1.05	4	−0.94	−0.44X+ 8.56
1.06 to 1.10	25	.10	.09X+ .92
1.11 to 1.15	38	.17	.17X− .08
1.16 to 1.20	69	.11	.23X+ .82
1.21 to 1.25	130	.18*	.45X− 1.75
1.26 to 1.30	230	−.07	−.20X+10.87
1.31 to 1.35	326	−.26**	−.81X+22.75
1.36 to 1.40	403	−.28**	−.78X+24.51
1.41 to 1.45	349	−.32**	−.81X+25.83
1.46 to 1.50	228	−.23	−.63X+24.19
1.51 to 1.55	118	−.31	−.78X+27.34
Total	1,920		
Rotation 3—fall plowed:			
1.01 to 1.05	18	0.27	0.10X+ 0.49
1.06 to 1.10	51	.06	.06X+ 1.89
1.11 to 1.15	138	.05	.06X+ 2.61
1.16 to 1.20	279	.05	.10X+ 3.76
1.21 to 1.25	388	−.13*	−.26X+10.97
1.26 to 1.30	526	−.09*	−.17X+10.47
1.31 to 1.35	530	−.19**	−.32X+14.37
1.36 to 1.40	364	−.27**	−.42X+16.46
1.41 to 1.45	186	−.31**	−.50X+17.90
1.46 to 1.50	81	−.29**	−.57X+18.70
1.51 to 1.55	21	.21	.65X+ 3.13
Total	2,582		

[1] *=Significant at 5-percent level, and **=significant at 1-percent level.

Correlation coefficients for the relationship between penetrometer readings and bulk-density measurements at various soil-moisture intervals were all significant at the 1-percent level except one (table 3). Regression coefficients in the regression equations for spring plowing generally decreased as soil moisture increased, an indication that bulk density has greater influence on penetrometer readings at low- than at high-moisture contents. Although regression coefficients under fall plowing were high in the first two moisture intervals, there was no consistent trend in the remaining moisture intervals.

TABLE 3.—*Correlation and regression of penetrometer readings and bulk density at various moisture intervals. Mandan, N. Dak.*

Moisture interval, percent	Number of comparisons	Correlation [1] coefficient	Regression equation
Rotation 2—spring plowed:			
11. 1 to 12. 0	53	0. 85**	42. 57X−44. 14
12. 1 to 13. 0	125	. 67**	44. 39X−47. 41
13. 1 to 14. 0	250	. 54**	35. 19X−34. 65
14. 1 to 15. 0	346	. 62**	35. 67X−37. 42
15. 1 to 16. 0	404	. 53**	31. 98X−33. 54
16. 1 to 17. 0	383	. 59**	31. 53X−33. 08
17. 1 to 18. 0	212	. 51**	28. 36X−28. 59
18. 1 to 19. 0	93	. 44**	21. 14X−19. 90
19. 1 to 20. 0	40	. 48**	27. 62X−25. 90
20. 1 to 21. 0	14	. 57**	20. 73X−18. 06
Total	1, 920		
Rotation 3—fall plowed:			
11. 1 to 12. 0	72	0. 66**	30. 63X−29. 84
12. 1 to 13. 0	233	. 65**	31. 63X−31. 97
13. 1 to 14. 0	433	. 31**	14. 81X−10. 25
14. 1 to 15. 0	420	. 43**	20. 16X−17. 91
15. 1 to 16. 0	425	. 43**	19. 75X−18. 11
16. 1 to 17. 0	330	. 44**	17. 96X−15. 71
17. 1 to 18. 0	293	. 47**	19. 94X−17. 93
18. 1 to 19. 0	206	. 59**	22. 78X−21. 85
19. 1 to 20. 0	134	. 46**	20. 97X−19. 62
20. 1 to 21. 0	36	. 41*	16. 71X−13. 47
Total	2, 582		

[1] *=Significant at 5-percent level, and **=significant at 1-percent level.

For the soil under study, bulk density had a greater influence on penetrometer readings than did soil moisture. Soil moisture became an important factor influencing penetrometer readings when bulk-density values were greater than 1.30. Jamison and Weaver (*5*), working at Auburn, Ala., stated that "soil macro-porosity has more effect on soil hardness than moisture content within the moisture range between field capacity and air dryness." Their results would be in agreement with those reported herein. However, Shaw, *et al.* (*8*), working in Ohio, concluded that "soil moisture is the dominant factor influencing the force required to push a probe into the soil."

Penetrometer and bulk-density curves (figure 9) show the difference in plowpan formation between spring- and fall-plowed plots. Each curve is an average of 30 locations. Since differences between spring and fall plowing may have accumulated over a long period of years, it seemed desirable to determine whether the immediate effect of plowing could be detected or, in other words, to determine what effect a single plowing operation would have on plowpan formation.

Depth of plowing was approximately 6 inches, which can be noted by the sharp break in penetrometer curves at that depth. As would be expected, plowing reduced the penetrometer and bulk-density values within the plow depth. Below this depth there was little change in penetrometer readings before and after spring plowing. However, the readings were considerably lower after fall plowing, which may be explained by differences in soil moisture. Although the areas were wet before sampling to obtain uniform soil-moisture curves, uniformity was not achieved. The soil was more moist after plowing, which would then cause lower penetrometer readings.

Bulk-density measurements should not be so sensitive to soil moisture as the penetrometer reading and thus the bulk-density curves presented in figure 9 should be more accurate than those of the penetrometer. The bulk-density curves show an increase at the 3-inch depth and a decrease at the 5-inch depth, followed by further increases in the 7- to 8-inch depth. The decrease at the 5-inch depth was attributed to straw that had been turned under at the time of plowing which would reduce the bulk density.

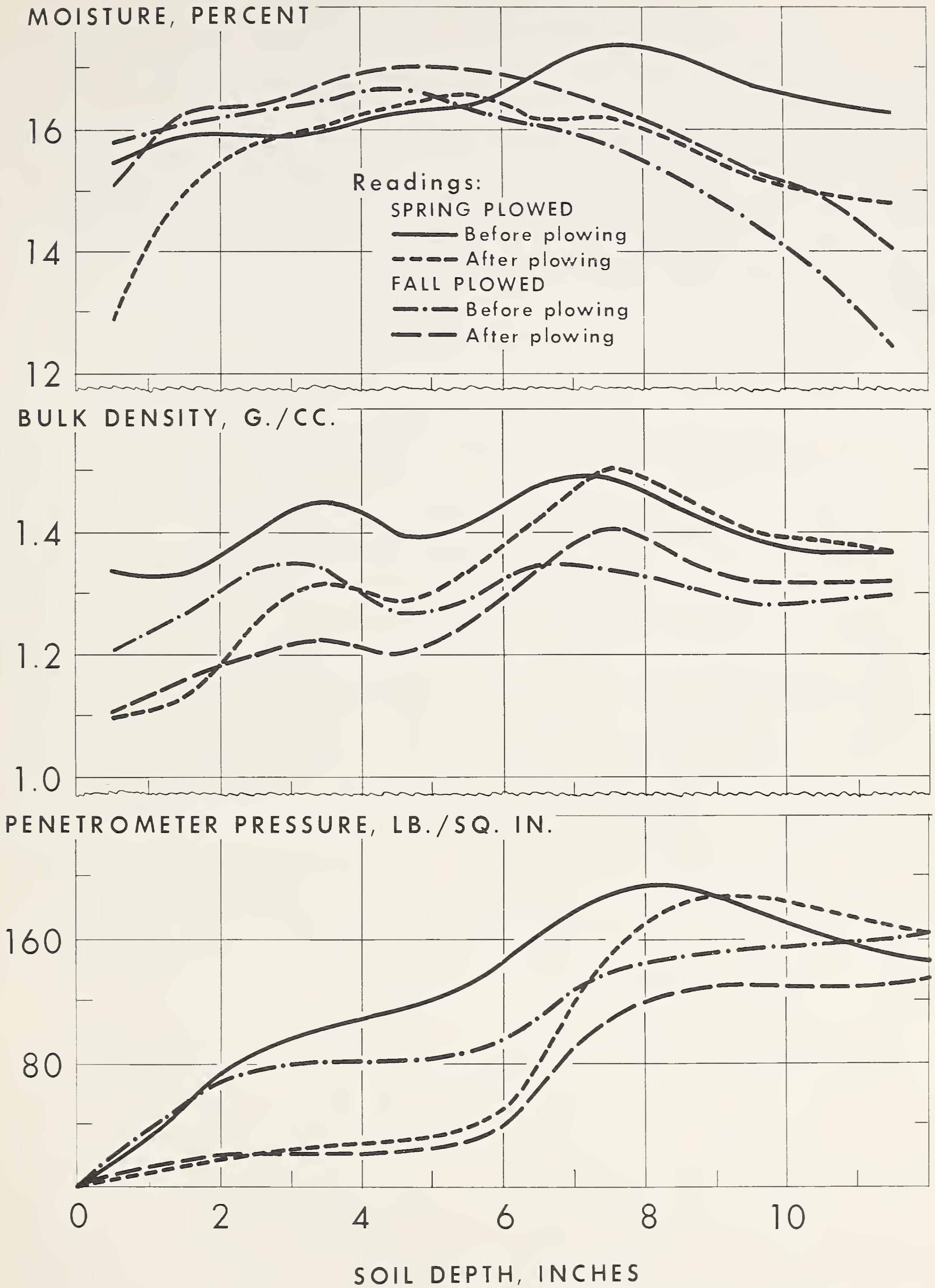

FIGURE 9.—Effect of spring and fall plowing and soil moisture on penetrometer-pressure and bulk-density determinations. Mandan, N. Dak., 1946 and 1947.

553258 O—60——3

Apparently the penetrometer was not sufficiently sensitive to record the increase in the third inch and the decrease in the fifth inch.

At the 7- or 8-inch depth, there was a slight increase in bulk density from spring plowing but a much greater increase from fall plowing. A check of the weather records revealed that sufficient rainfall was received just before fall plowing to wet the soil below the plow depth, which may account for the increase in bulk density during fall plowing in this particular instance.

From these results it is apparent that the effect of a single plowing operation could be detected when soil-moisture conditions were favorable for compaction.

Penetrometer, bulk-density, and soil-moisture measurements were made in the fall and in the following spring on both fall- and spring-plowed plots to determine what effect freezing and thawing might have on correcting the plowpan formation. The readings in the fall were taken after plowing and those in the spring, before plowing. The results are presented graphically in figure 10.

The penetrometer curves indicate that under spring plowing, the penetrometer readings of the plowpan layer were reduced over winter, and that there was no change in that layer under fall plowing. The soil-moisture curves, however, show that soil moisture under spring plowing was considerably less in the fall than in the following spring. This would probably account for the higher penetrometer readings in the fall.

Bulk-density measurements, on the other hand, were higher in the spring under both spring and fall plowing. Since bulk density would be influenced less by differences in soil moisture, the bulk-density curves should be more reliable than the penetrometer curves. Apparently under the conditions of this experiment, freezing and thawing had no favorable effect in reducing the bulk density of the soil and, in fact, soil density was actually increased over winter.

Penetrometer, bulk-density, and soil-moisture measurements were made in the spring and in the following fall on both spring- and fall-plowed plots to determine changes in soil compaction as shown by these measurements over summer. The results are presented graphically in figure 11. The penetrometer curves indicated that there was considerable increase in soil compaction over summer for both spring- and fall-plowed plots. However, the penetrometer curves were apparently influenced to a considerable extent by differences in soil moisture and, therefore, do not present a true picture.

The bulk-density curves show that the surface soil became more dense over summer, as would be expected, but there was very little change below 6 or 7 inches.

Studies at Woodward

In the early summer of 1955 a study was conducted at Woodward to measure the resistance to penetration of the plowpan on 20 of the MC series plots in field A. The objectives of this study were (1) to assess differences in penetrability of plowpans formed under the different cropping and cultural practices, (2) to determine the relationship between penetrability and bulk density of the soil, and (3) to determine the relationship between penetrability and moisture content of the soil.

The penetrometer used at Mandan was also used at Woodward, where it was mounted on a 3-point hitch, so that it could be moved with a light tractor (fig. 12). The studies were made on the spring shallow-plowed plot A; fall deep-plowed plot B; and on alternate crop and fallow plots C and D plowed deep after each crop of the milo, corn, broomcorn, kafir, and sorgo series. The soil was at approximate field capacity. The plots had recently been tilled with a one-way plow (disk tiller) with a Miller Basin Tiller pulled behind it. The soil had been settled by rain after tillage but was still pitted and somewhat loose and rough.

Five penetrometer readings were made on each of the 20 plots. Locations were at random but, in general, were from the northeast to the southwest corners of each plot. It was necessary to use areas between the basin tiller pits and often to level them. The penetrometer was operated until the pressure had reached a maximum point and had subsided from that maximum. However, it was always operated until the point had reached a depth of 12 inches or more. At each location, two sets of soil samples were also taken—for bulk-density and for soil-moisture determinations.

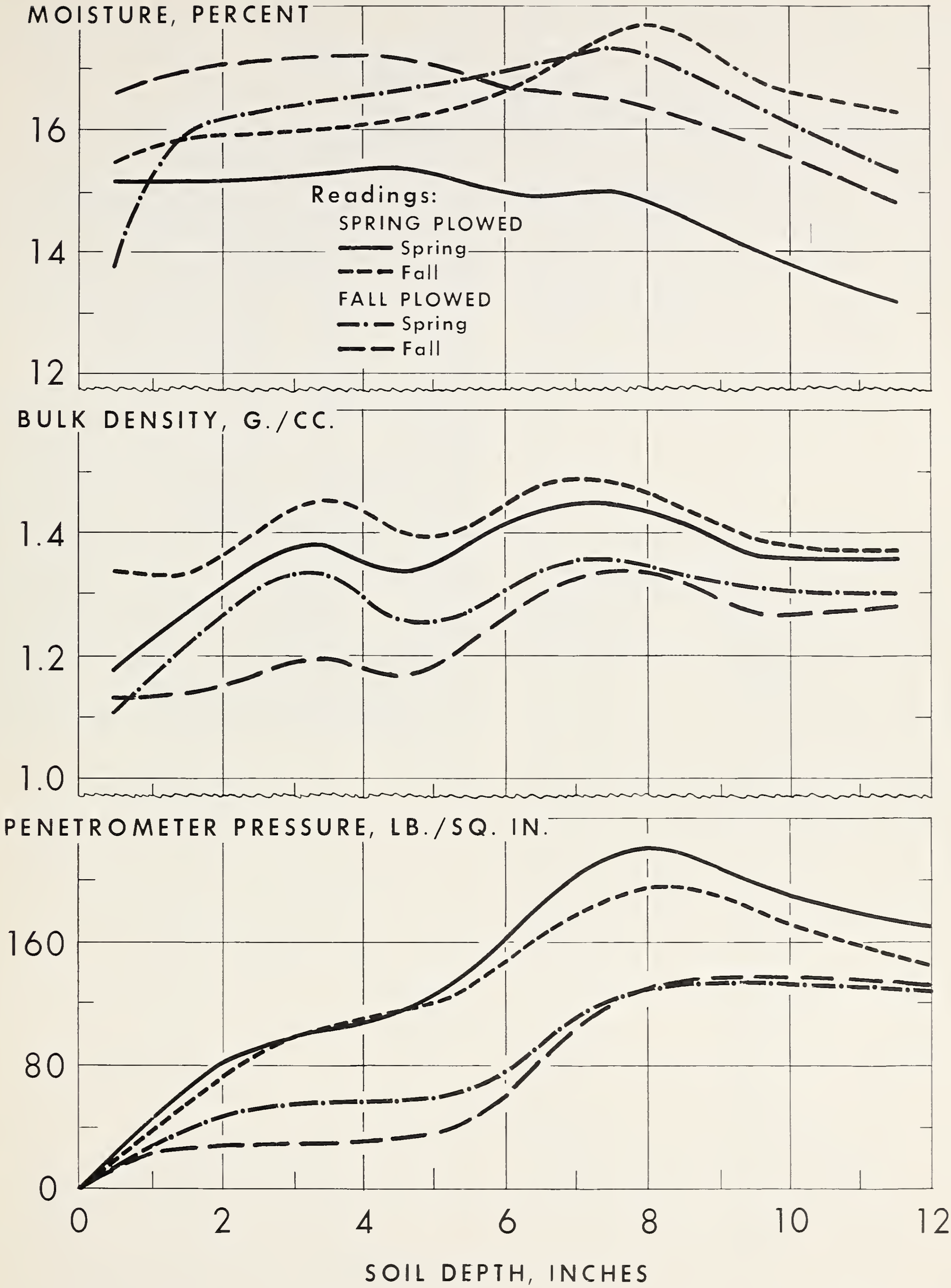

FIGURE 10.—Effect of freezing and thawing and soil moisture on penetrometer and bulk-density determinations for both spring and fall plowing. Mandan, N. Dak., 1946 and 1947.

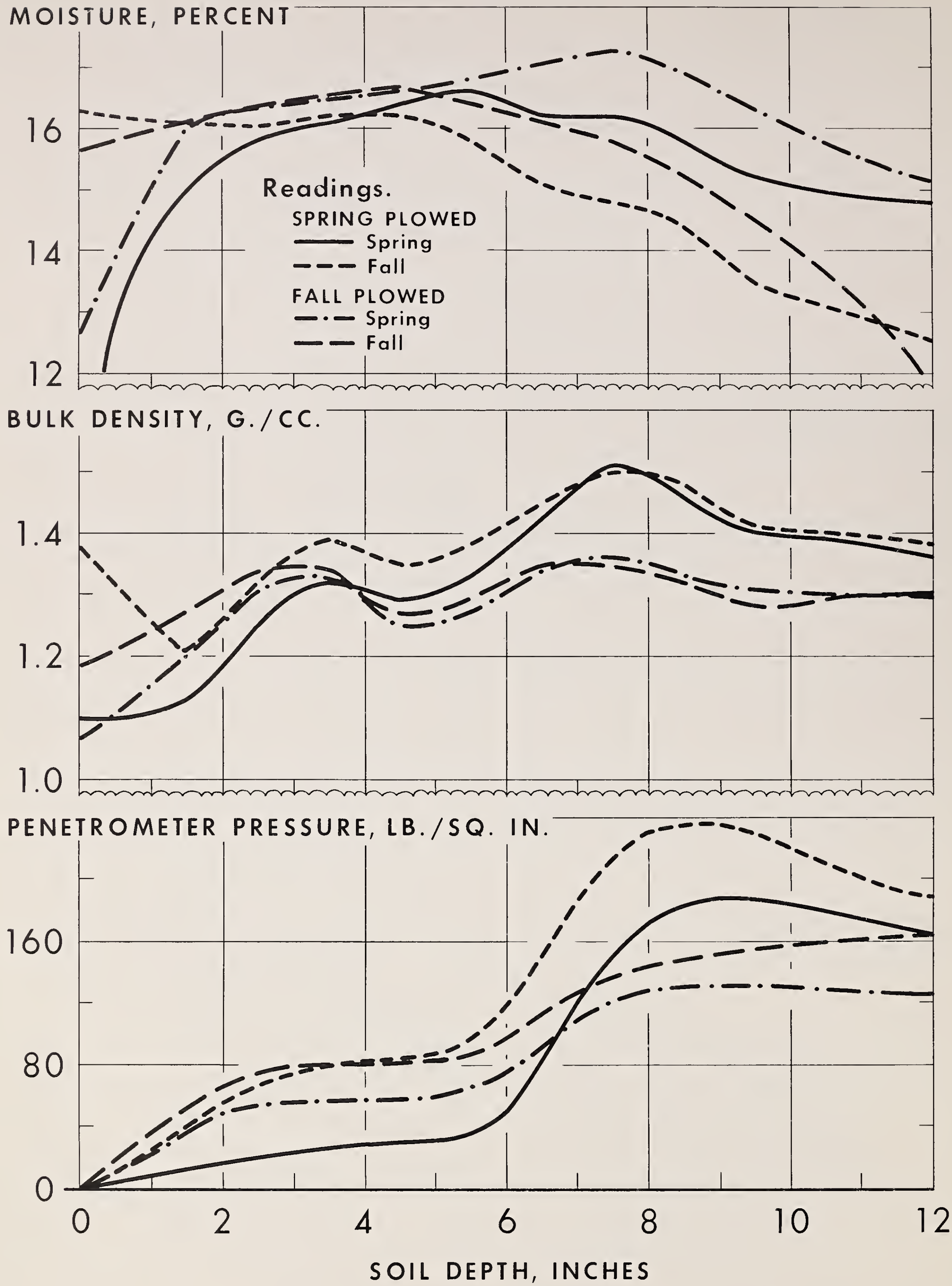

FIGURE 11.—Changes in penetrometer and bulk-density determinations over summer for both spring and fall plowing, together with soil-moisture determinations. Mandan, N. Dak., 1946 and 1947.

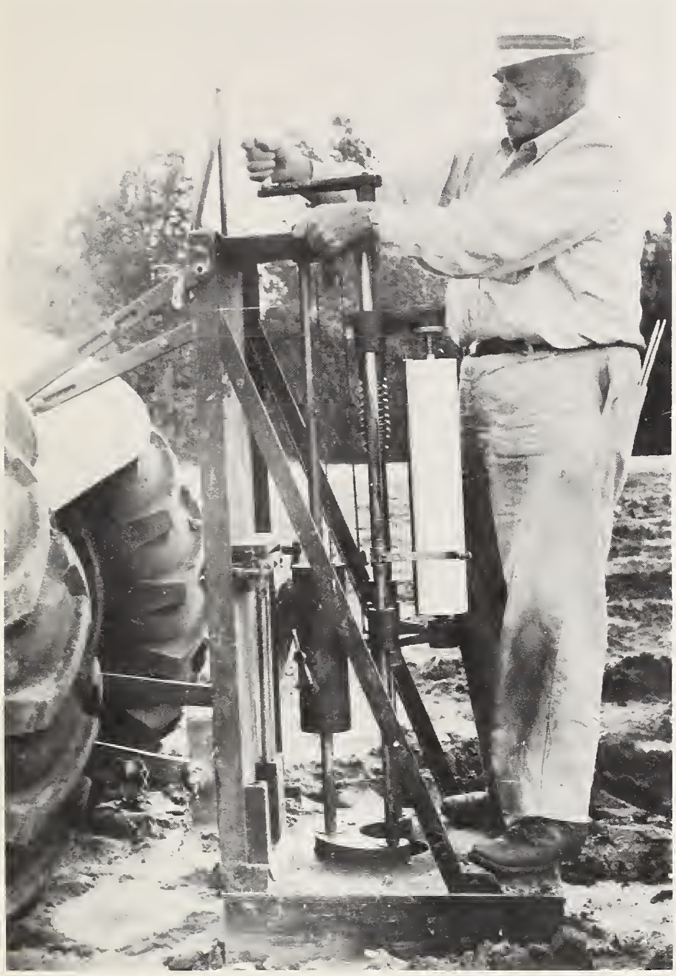

FIGURE 12.—Operating penetrometer used in these experiments.

A modification of the Mandan tube, manufactured by a local machine shop, was used to collect the samples. This tube had a conventional soil tube point. Above that point the tube was cut halfway through at 1-inch intervals, so that a spatula or other cutting instrument could be inserted to cut the column of soil into 1-inch vertical sections (fig. 13). The samples were composited by depth for each plot.

Summaries of average penetration-pressure, bulk-density, and soil-moisture data are presented in tables 4, 5, and 6, respectively. Data for the two alternate crop and fallow plots for each crop are averaged by depths and considered as one plot.

Penetration-pressure data were subjected to an analysis of variance. There was a significant difference in average pressure required to penetrate 1 inch of soil among crops, among tillage treatments, and among depths. Significant interactions between depth and tillage, and between crop and tillage were also noted. The multiple range test of Duncan (*3*) showed that the average pressure required to penetrate 1 inch of soil on the milo plots was significantly less than that on the corn, broomcorn, kafir, and sorgo plots. There were no significant differences among these plots.

On an average 171.6 p. s. i. of pressure was required to penetrate 1 inch of soil on plot A, while the value for plot B was 224.8 p. s. i.; plots C and D, averaged 251.5 p. s. i. The pressures required to penetrate the soil under the three methods of tillage were shown to be significantly different from each other by the multiple range test.

Penetration pressure increased with depth until the probe passed through the plowpan and then decreased, as can be observed in table 4.

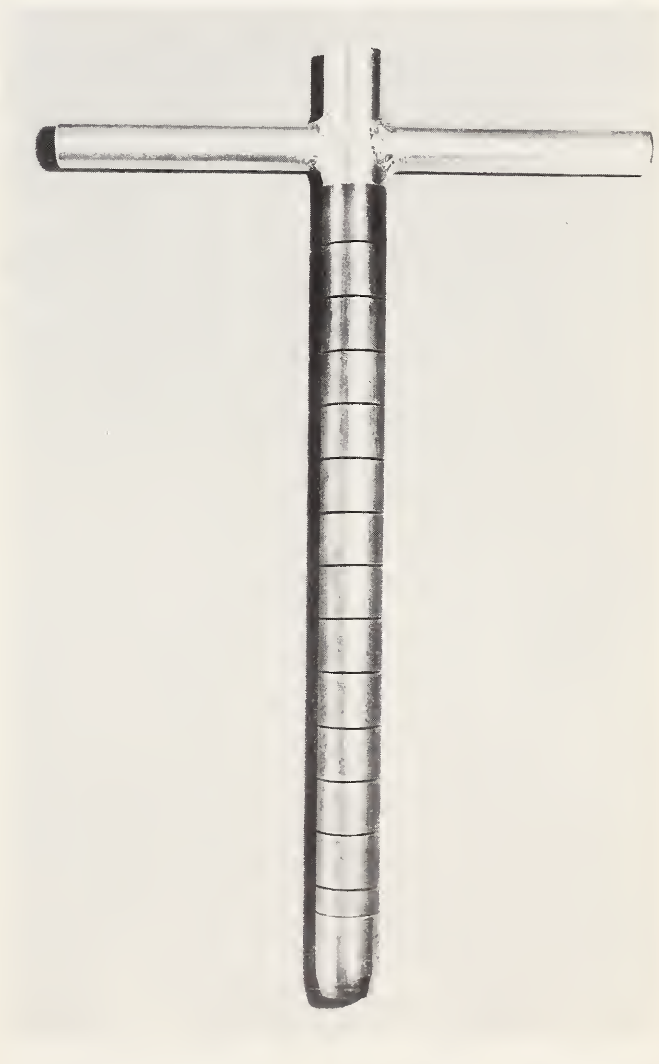

FIGURE 13.—Bulk-density tube used in sampling at Woodward, Okla.

TABLE 4.—*Summary of penetration pressure data on MC milo, corn, broomcorn, kafir, and sorgo plots, field A—Woodward, Okla. Average of 5 locations per plot*

Crop and plot[1]	Penetration pressures at soil depth of—												
	1 inch	2 inches	3 inches	4 inches	5 inches	6 inches	7 inches	8 inches	9 inches	10 inches	11 inches	12 inches	Average
	P.s.i.	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*
Milo:													
A	0	0	0	0	44.8	119.6	231.2	259.6	262.8	261.6	259.2	254.8	141.1
B	0	0	14.0	51.2	136.8	234.4	349.2	410.4	415.6	410.4	427.2	438.0	240.6
C–D[2]	0	8.0	23.0	49.6	93.6	161.8	270.0	352.4	385.2	402.0	403.0	398.0	212.2
Average	0	2.6	12.3	33.6	91.7	171.9	283.5	340.8	354.5	358.0	363.1	363.6	198.0
Corn:													
A	0	0	0	34.0	132.0	264.0	306.4	310.8	295.6	257.6	238.8	223.6	171.9
B	0	0	32.0	48.0	125.2	252.0	346.4	396.4	424.0	413.2	392.0	363.2	232.7
C–D[2]	10.0	39.8	48.0	87.8	152.2	260.2	363.0	415.6	420.8	404.0	374.6	335.2	242.6
Average	3.3	13.3	26.7	56.6	136.5	258.7	338.6	374.3	380.1	358.3	335.1	307.3	215.7
Broomcorn:													
A	0	0	0	16.0	114.8	246.4	288.4	284.0	264.4	250.4	245.2	240.4	162.5
B	0	18.0	62.4	100.4	140.0	236.4	332.8	380.4	394.4	432.8	440.0	406.8	245.4
C–D[2]	0	14.0	37.4	86.6	185.6	308.8	383.4	445.4	487.4	488.4	466.4	435.0	278.2
Average	0	10.7	33.3	67.7	146.5	263.9	334.9	369.9	382.1	390.5	383.9	360.7	228.7
Kafir:													
A	0	0	0	23.2	62.0	156.0	292.4	411.2	448.0	422.0	349.6	301.2	205.6
B	0	0	0	43.2	100.4	204.8	309.2	345.6	359.6	372.0	370.8	343.2	204.1
C–D[2]	6.0	28.6	50.6	78.0	143.6	274.0	314.2	379.6	420.0	438.2	451.6	444.0	252.4
Average	2.0	9.5	16.9	48.8	102.0	211.6	305.3	378.8	409.2	410.7	390.7	362.8	220.7
Sorgo:													
A	0	0	0	16.0	69.2	178.8	309.2	328.4	328.4	314.0	297.2	280.0	176.8
B	0	0	14.0	24.8	100.8	195.6	263.2	307.6	359.6	389.6	382.0	375.2	201.0
C–D[2]	0	21.6	55.4	85.6	158.2	280.0	392.8	461.0	487.4	476.2	443.8	404.0	272.2
Average	0	7.2	23.1	42.1	109.4	218.1	320.7	365.7	391.8	393.3	374.3	353.1	216.7
Depth means	0.1	8.7	22.5	49.8	117.2	224.8	316.6	365.9	383.5	382.2	369.4	349.5	216.0

[1] Plot A was shallow plowed in the spring; plot B, deep plowed in the fall; plots C and D were alternate crop and fallow.

[2] Average pressures for C and D plots.

Bulk-density data (table 5) were treated statistically in the same manner as the penetration data. Significant differences were found among crops, among tillage methods, and among depths. Significant interactions between depth and tillage, between crop and depth, and between crop and tillage were noted also. The multiple-range test showed that the average bulk-density value on the milo plots was significantly lower than that on the corn, sorgo, broomcorn, or kafir plots. There were no significant differences among these plots.

Average bulk-density values for the three tillage methods were 1.54 for plot A, 1.62 for plot B, and averaged 1.67 for plots C and D. The multiple-range test showed the bulk densities for the three tillage methods to be significantly different from each other.

With both penetration pressure and bulk density being significantly different among crops, among tillage treatments, and among depths, and with compaction as a logical cause for increased penetration pressure, one would expect to find a high correlation between penetration pressure and bulk density. The coefficient of correlation (r) was 0.47, which is significant at the 1-percent level. The coefficient of determination (0.22), however, indicates that only 22 percent of the variance is attributable to linear regression. This does not indicate a close linear relationship between penetration pressure and bulk density.

TABLE 5.—*Summary of bulk-density data on MC milo, corn, broomcorn, kafir, and sorgo plots, field A—Woodward, Okla., 1955. One determination on 10 subsamples per plot*

Crop and plot[1]	Bulk density at soil depth of—												
	1 inch	2 inches	3 inches	4 inches	5 inches	6 inches	7 inches	8 inches	9 inches	10 inches	11 inches	12 inches	Average
Milo:	*G./cc.*	*G./cc.*	*G./cc.*	*G./cc.*	*G./cc.*	*G./cc.*	*G./cc.*	*G./cc.*	*G./cc.*	*G./cc.*	*G./cc.*	*G./cc.*	*G./cc.*
A	1. 33	1. 33	1. 36	1. 34	1. 35	1. 48	1. 65	1. 38	1. 53	1. 43	1. 35	1. 58	1. 43
B	1. 38	1. 38	1. 46	1. 38	1. 68	1. 65	1. 64	1. 65	1. 61	1. 61	1. 66	1. 64	1. 56
C–D[2]	1. 68	1. 50	1. 66	1. 50	1. 57	1. 57	1. 67	1. 56	1. 54	1. 69	1. 49	1. 70	1. 59
Average	1. 46	1. 40	1. 49	1. 41	1. 53	1. 57	1. 65	1. 53	1. 56	1. 58	1. 50	1. 64	1. 53
Corn:													
A	2. 17	1. 53	1. 54	1. 59	1. 69	1. 60	1. 57	1. 55	1. 52	1. 51	1. 45	1. 48	1. 60
B	1. 64	1. 50	1. 59	1. 54	1. 67	1. 70	1. 71	1. 73	1. 65	1. 68	1. 55	1. 56	1. 63
C–D[2]	1. 71	1. 48	1. 61	1. 60	1. 70	1. 61	1. 67	1. 66	1. 70	1. 62	1. 56	1. 59	1. 63
Average	1. 84	1. 50	1. 58	1. 58	1. 69	1. 64	1. 65	1. 65	1. 62	1. 60	1. 52	1. 54	1. 62
Broomcorn:													
A	1. 51	1. 44	1. 50	1. 63	1. 47	1. 61	1. 60	1. 64	1. 58	1. 63	1. 54	1. 58	1. 56
B	1. 38	1. 46	1. 56	1. 59	1. 63	1. 66	1. 73	1. 77	1. 77	1. 89	1. 77	1. 70	1. 66
C–D[2]	1. 73	1. 51	1. 66	1. 71	1. 80	1. 74	1. 76	1. 80	1. 80	1. 77	1. 68	1. 72	1. 72
Average	1. 54	1. 47	1. 57	1. 64	1. 63	1. 67	1. 70	1. 74	1. 72	1. 76	1. 66	1. 67	1. 65
Kafir:													
A	1. 41	1. 49	1. 58	1. 51	1. 58	1. 57	1. 64	1. 65	1. 69	1. 66	1. 54	1. 52	1. 57
B	1. 59	1. 51	1. 61	1. 52	1. 68	1. 63	1. 65	1. 72	1. 71	1. 87	1. 66	1. 65	1. 65
C–D[2]	1. 75	1. 56	1. 65	1. 68	1. 70	1. 82	1. 81	1. 77	1. 85	1. 88	1. 76	1. 75	1. 75
Average	1. 58	1. 52	1. 61	1. 57	1. 65	1. 67	1. 70	1. 71	1. 75	1. 80	1. 65	1. 64	1. 66
Sorgo:													
A	1. 55	1. 44	1. 57	1. 53	1. 58	1. 55	1. 64	1. 60	1. 61	1. 66	1. 56	1. 50	1. 57
B	1. 43	1. 49	1. 59	1. 62	1. 62	1. 58	1. 70	1. 65	1. 68	1. 70	1. 63	1. 65	1. 61
C–D[2]	1. 67	1. 56	1. 69	1. 68	1. 73	1. 73	1. 72	1. 72	1. 73	1. 71	1. 65	1. 59	1. 68
Average	1. 55	1. 50	1. 62	1. 61	1. 64	1. 62	1. 69	1. 66	1. 67	1. 69	1. 61	1. 58	1. 62
Depth means	1. 59	1. 48	1. 57	1. 56	1. 63	1. 63	1. 67	1. 66	1. 66	1. 69	1. 59	1. 61	1. 62

[1] Plot A was shallow plowed in the spring; plot B, deep plowed in the fall; plots C and D were alternate crop and fallow.

[2] Average bulk densities for C and D plots.

Average bulk density and penetration pressure for all 20 plots are plotted by depth in figure 14.

The fact that the penetration pressure and bulk-density lines are reasonably parallel from 2 to 7 inches and from 7 to 12 inches but crossed each other, suggested that some other factor might be interfering with the relationship between penetration pressure and bulk density. The data from the 2- to 12-inch depths were separated into two groups according to whether or not the soil had ever been plowed. The 1- to 2-inch depth was discarded due to compaction and soil displacement during the measurement. The plowed group (above depth of plowing) consisted of 105 samples, including the 2-, 3-, 4-, 5-, and 6-inch samples from all plots and the 7-, 8-, and 9-inch depths from the B and C-D plots. The unplowed group consisted of 60 samples including the 7-, 8-, and 9-inch depths from the A plots and samples from all plots at the 10-, 11-, and 12-inch depths. Correlation coefficients between bulk density and penetration pressure for the plowed and unplowed groups were 0.69 and 0.67, respectively. This constitutes major improvement over the coefficient of 0.47 for all samples grouped together.

The change in the relationship at the depth of plowing is evidently due to a textural change in the soil. The texture is homogeneous to the depth of plowing and again below plow depth, but the two soil layers are different in texture.

A further reason for the rather low correlation between bulk density and penetration pressure might have been due to the fact that the samples

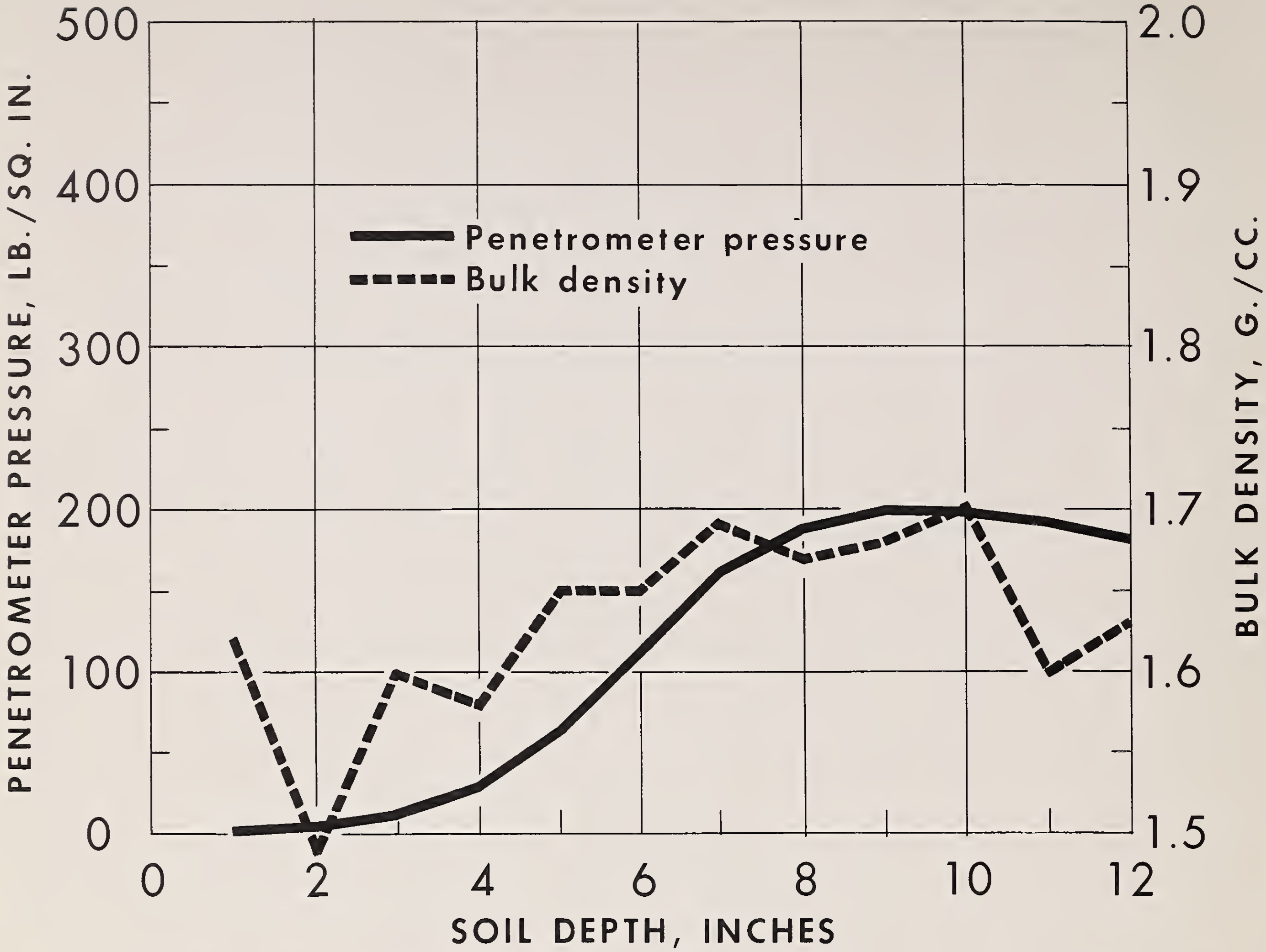

FIGURE 14.—Penetration pressure and bulk-density determinations by depths for all plots. Woodward, Okla., 1955.

for bulk density were composited by plots rather than keeping them separate by locations within the plots. Further study was undertaken with a Cornell penetrometer (*9*) [4] in June 1957 on the shallow- and deep-plowed kafir plots. Six penetrometer readings were taken at intervals of 2 to 3 feet on each plot. Samples for bulk-density determinations were taken within a few inches of each penetrometer location and kept separate for each location. Bulk density and penetration pressure plotted against depth are shown in figures 15 and 16.

The relationships between bulk density and depth and between penetrometer pressure and depth changed at the approximate depth of plowing in both instances. The linear correlation $r = 0.718$ between bulk density and penetrometer pressure was calculated for the deep-plowed plot. By statistical test this was significantly different from zero at the 5-percent level. The correlation for the shallow-plowed plot was calculated to be $r = 0.518$, which did not test significantly different from zero. However, these two correlations did not test significantly different from each other.

Significant linear correlations on the deep-plowed plot (fig. 16) and not on the shallow-plowed plot (fig. 15) may be due to a greater depth of soil of uniform texture on the deep-plowed plot, or may result from a lack of range in penetrometer pressure and bulk density on the shallow-plowed plot.

[4] Mention in this publication of commercially manufactured equipment or specific products does not imply endorsement by the U.S. Department of Agriculture over similar equipment or products not mentioned.

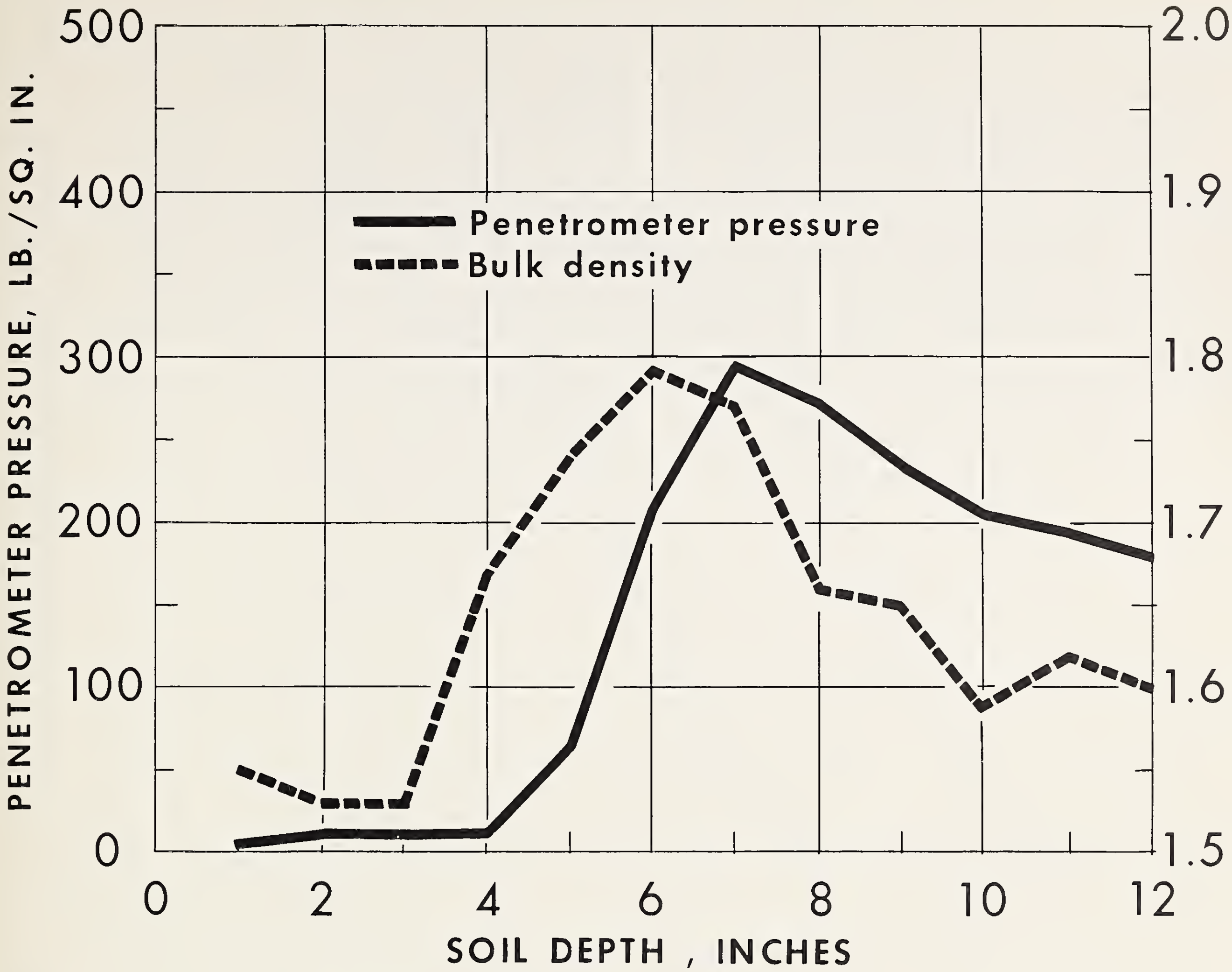

FIGURE 15.—Comparison of penetrometer-pressure and bulk-density determinations—shallow plowing. Woodward, Okla., 1957.

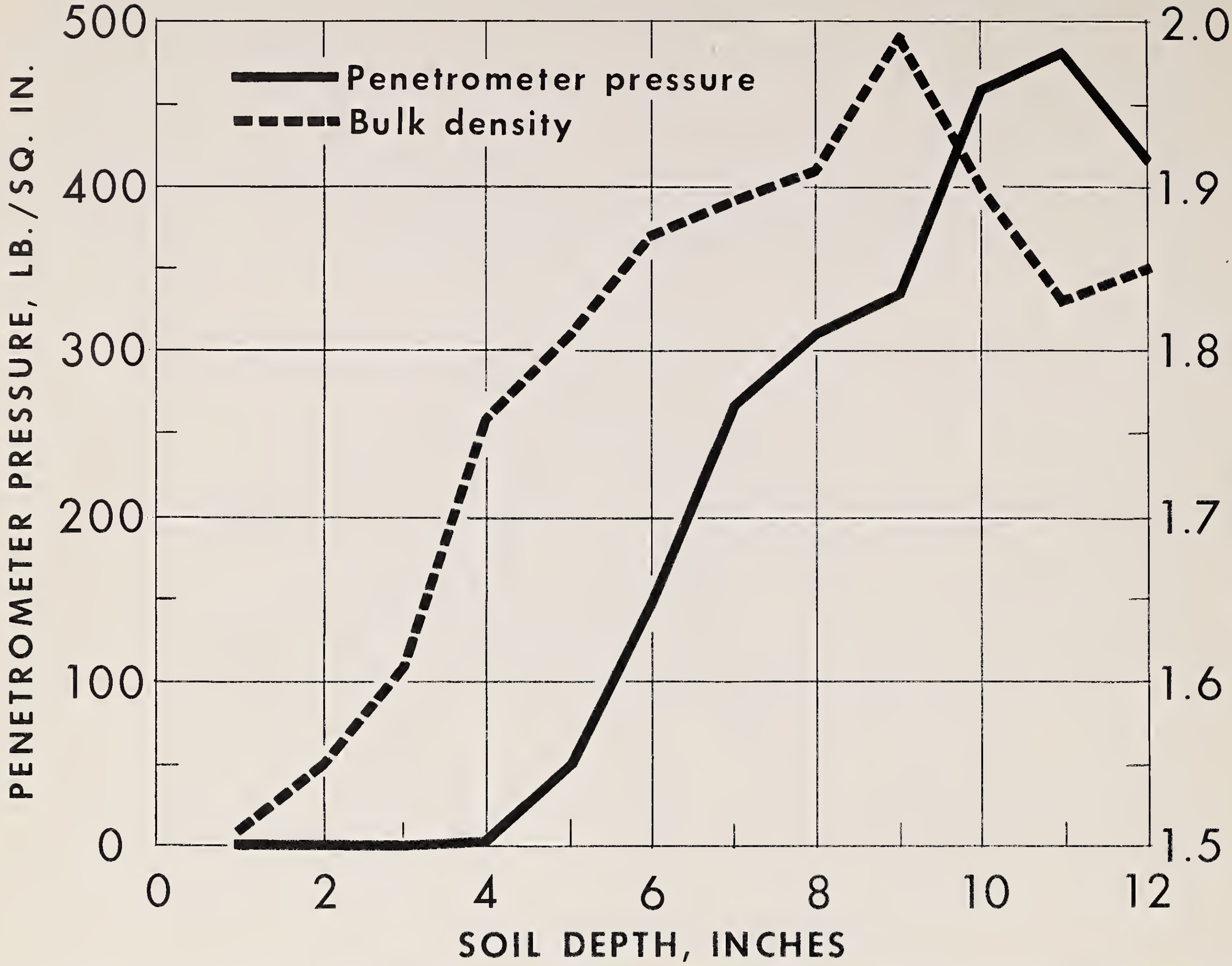

FIGURE 16.—Comparison of penetrometer-pressure and bulk-density determinations—deep plowing. Woodward Okla., 1957.

As stated previously, the soil was at approximate field capacity when penetration and bulk-density data were taken. If the moisture content of the soil had been appreciably below field capacity, a negative correlation between penetration pressure and soil moisture would have been expected (the lower the soil moisture, the higher the penetration pressure). Instead, a significant positive correlation between soil moisture and penetration pressure was obtained ($r = 0.58$). It is believed that this was an instance when two variables paralleled each other (both penetration pressure and soil moisture increased with depth) but did not affect each other over the moisture range studied. The texture of the soil was finer below the plow depth than it was above it; thus, it had a higher moisture content at field capacity. Field capacity data are not available for all plots, but moisture equivalent data on kafir plots A and B (table 1) support this explanation.

The sorgo plots (table 6) contained a higher percentage of soil moisture than the others at sampling time. This was due to 0.44 inch of precipitation which fell after the other four crop areas were sampled but before the sorgo plots were sampled. The higher soil moisture apparently did not affect penetration pressure (no significant difference among corn, broomcorn, kafir, and sorgo). On an individual plot basis, soil moisture and penetration pressure were

TABLE 6.—*Summary of soil-moisture data on MC milo, corn, broomcorn, kafir, and sorgo plots, field A—Woodward, Okla., 1955. One determination on 10 subsamples per plot*

Crop and plot[1]	Soil moisture at soil depth of—												
	1 inch	2 inches	3 inches	4 inches	5 inches	6 inches	7 inches	8 inches	9 inches	10 inches	11 inches	12 inches	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Milo:													
A	7.7	8.6	8.8	8.9	9.4	9.7	10.9	11.4	12.1	11.9	11.3	10.9	10.1
B	7.4	8.5	8.9	9.0	9.0	9.0	9.2	10.0	10.4	10.5	10.5	11.0	9.5
C–D[2]	7.1	7.5	8.5	8.8	9.2	9.0	9.4	9.7	10.1	10.4	10.8	11.2	9.3
Average	7.4	8.2	8.7	8.9	9.2	9.2	9.8	10.4	10.9	10.9	10.9	11.0	9.6
Corn:													
A	7.2	8.1	8.9	9.1	9.1	10.4	11.3	10.9	10.7	10.5	10.2	9.7	9.7
B	5.6	8.0	8.6	9.0	9.2	9.1	9.1	9.8	9.8	10.4	10.4	10.1	9.1
C–D[2]	6.0	7.4	7.0	8.2	8.4	8.5	9.8	10.2	9.6	11.4	11.1	11.3	9.1
Average	6.3	7.8	8.2	8.8	8.9	9.3	10.1	10.3	10.0	10.8	10.6	10.4	9.3
Broomcorn:													
A	5.4	6.8	10.6	7.9	8.6	9.4	10.2	11.7	11.4	11.0	10.5	9.7	9.4
B	8.4	7.0	7.4	8.0	8.2	8.2	8.3	10.0	9.8	10.1	11.1	12.8	9.1
C–D[2]	6.9	8.1	8.3	8.5	8.8	8.7	8.8	9.8	11.3	12.1	12.2	12.0	9.6
Average	6.9	7.3	8.8	8.1	8.5	8.8	9.1	10.5	10.8	11.1	11.2	11.5	9.4
Kafir:													
A	6.7	7.1	7.9	8.0	8.6	8.6	9.3	9.8	10.1	10.3	11.2	10.7	9.0
B	7.0	7.8	8.2	8.9	8.9	9.3	8.7	8.4	8.4	9.3	9.4	10.1	8.7
C–D[2]	5.7	6.6	7.1	7.2	7.7	8.0	7.7	8.3	8.5	8.8	9.2	9.9	7.9
Average	6.5	7.2	7.7	8.0	8.4	8.6	8.6	8.8	9.0	9.5	9.9	10.2	8.5
Sorgo:													
A	9.7	10.5	10.4	11.0	10.8	10.5	11.3	11.6	11.3	11.1	10.8	10.5	10.8
B	9.2	10.1	10.5	11.0	10.5	9.4	9.7	9.3	8.9	9.6	9.7	9.6	9.8
C–D[2]	9.0	9.8	9.9	9.8	9.5	9.2	9.0	8.9	9.4	10.7	10.1	11.2	9.7
Average	9.3	10.1	10.3	10.6	10.3	9.7	10.0	9.9	9.9	10.5	10.2	10.4	10.1
Depth means	7.3	8.1	8.7	8.9	9.1	9.1	9.5	10.0	10.1	10.6	10.6	10.7	9.4

[1] Plot A was shallow plowed in the spring; plot B, deep plowed in the fall; plots C and D were alternate crop and fallow.

[2] Average moisture contents for C and D plots.

significantly correlated at the 5-percent level on one but not on the other three sorgo plots. On all other plots (milo, corn, broomcorn, and kafir) soil moisture and penetration pressure were found to be highly significantly correlated at the 1-percent level. The upper layers of the sorgo plots were probably above field capacity when the determinations were made.

ORGANIC-MATTER AND MECHANICAL-ANALYSIS STUDIES

For these analyses 6- by 15-inch cores were taken from the kafir shallow-plowed plot A and the deep-plowed plot B and from a virgin sod area about 200 yards from the plots. The soil on the sod area was thought to be comparable to that on the plots. The cores were taken into the laboratory, trimmed with a knife, and allowed to dry. Definite differences in color due to depth of plowing were apparent, as shown in figure 17. Samples by 1-inch vertical sections were taken from the faces of the cores and organic-matter content was determined by the wet digestion method of Walkley and Black (*10*). Similar cores were taken from locations adjacent to those from which the three original ones were obtained. These cores were also cut into 1-inch vertical sections, and mechanical analyses were determined by the pipette method described in Kilmer and Alexander (*6*).

Organic-matter data are presented in table 7 and a graphical presentation of the data is given in figure 18. If it is assumed that the quantity of organic matter contained in the virgin sod is representative of that contained on the cropped plots at the time cropping was initiated, then during 41 years of cropping the shallow- and deep-plowed plots had lost approximately 50 and 75 percent, respectively, of the original organic matter. On the shallow-plowed plot, organic matter at depths greater than 9 inches was comparable to that at the same depth on the virgin sod, whereas on the deep-plowed plot the organic matter at 15 inches was only about half that at comparable depths on the virgin sod and the shallow-plowed plot. Organic matter depletion took place below the depth of plowing in both instances.

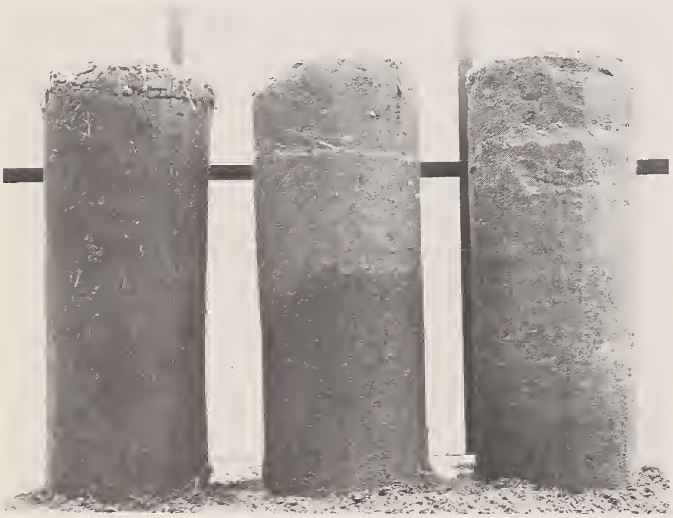

FIGURE 17.—Cores of soil 6 by 15 inches. Sod left, kafir plot A center, and kafir plot B right. Woodward, Okla., 1955.

TABLE 7.—*Organic matter by 1-inch depths in virgin sod and cultivated land.*[1] *Woodward, Okla., 1955*

Depth, inches	Virgin sod	Shallow plowed [2]	Deep plowed [3]
	Percent	*Percent*	*Percent*
0 to 1	4. 43	0. 69	0. 44
1 to 2	2. 59	. 51	. 44
2 to 3	2. 22	. 52	. 45
3 to 4	1. 88	. 56	. 41
4 to 5	1. 59	. 52	. 33
5 to 6	1. 47	. 62	. 39
6 to 7	1. 44	. 54	. 33
7 to 8	1. 20	. 83	. 35
8 to 9	1. 18	. 97	. 25
9 to 10	1. 08	1. 08	. 32
10 to 11	1. 12	1. 12	. 27
11 to 12	1. 11	. 99	. 48
12 to 13	1. 04	. 98	. 58
13 to 14	1. 05	1. 04	. 59
14 to 15	1. 03	1. 11	. 56
Average [4]	1. 63	. 81**	. 41**

[1] Analysis made at Blackland Experiment Station, Temple, Tex.

[2] Samples from old MC kafir shallow-plowed plot A, 1914–55.

[3] Samples from old MC kafir deep-plowed plot B, 1914–48; both plots shallow plowed with a one-way plow, 1949–55. Both plots in grain sorghum 1914–55.

[4] L.S.D. for treatment averages:
At the 5-percent level—0.303.
At the 1-percent level—0.408.

**=Significant at the 1-percent level.

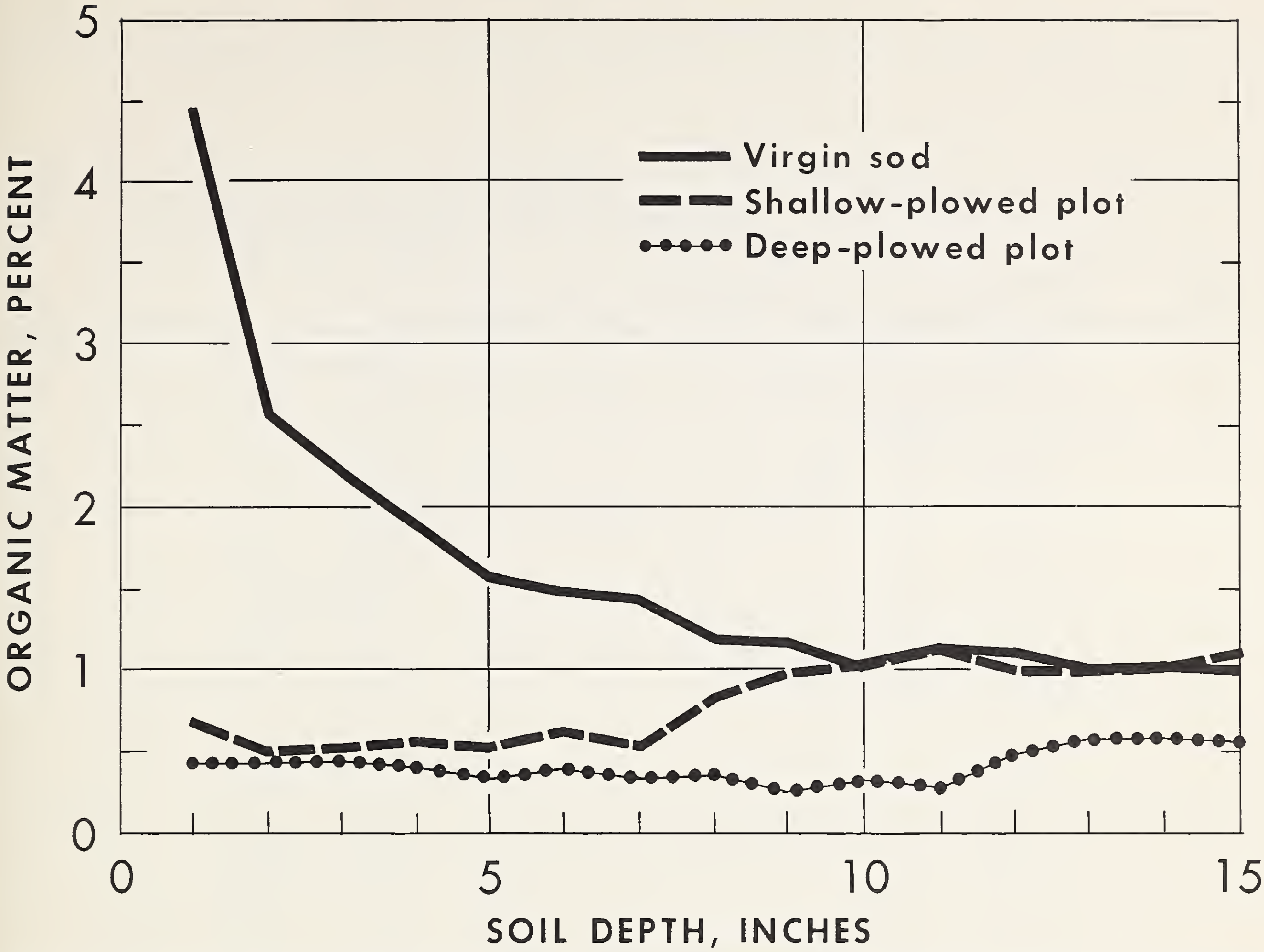

FIGURE 18.—Organic matter in inch layers in virgin sod and cultivated land—Pratt fine sandy loam. Woodward, Okla., 1955.

Mechanical analysis data are presented in table 8 and graphical presentations of the data are shown in figures 19, 20, and 21. Differences in mechanical composition between the sod profile and the two cultivated profiles indicate that the sod profile is finer in texture than the cultivated profiles and thus is not truly comparable with them. The relative uniformity of the upper 7 inches of the shallow-plowed profile and the break in sand and clay content between depths of 7 and 9 inches indicate that the plot was plowed at least to a depth of 7 inches sometime during its history of cultivation. Mechanical analysis of the deep-plowed plot indicates that it probably had not been plowed deeper than 8 or 8½ inches. Depths of plowing on the shallow- and deep-plowed plots during the 1914–48 period were supposed to have been 5 and 8 inches, respectively.

Statistical analysis of the total sand, total silt, and total clay fractions show that there is a significant difference between profiles in all three fractions. However, there is no significant difference in sand or silt with depth, but there is a significant difference in clay content. In the shallow-plowed profile, the 7- to 15-inch layer contains on an average 114.8 percent more clay than the 0- to 7-inch layer, whereas in the deep-plowed profile the 9- to 15-inch layer contains on an average 78.7 percent more clay than the 0- to 9-inch layer. However, there does not appear to be a concentration of any particular-sized fraction in the plowpans. The plowpan zone begins at 7½ inches on the shallow-plowed plot and at 10½ inches on the deep-plowed plot. In both, the particle size distribution in the plowpans is

TABLE 8.—*Mechanical analysis* [1] *showing percentages of various sizes* [2] *of soil particles, by inch layers from 6 by 15 inch cores from : Virgin sod, and kafir shallow-plowed plot A and deep-plowed plot B. Woodward, Okla., 1956*

Depth, inches	Sand							Silt		Clay 0.002
	Total	Very coarse 2–1	Coarse 1–0.5	Medium 0.5–0.25	Fine 0.25–0.2	Fine 0.2–0.1	Very fine 0.1–0.05	Coarse and medium 0.05–0.02	Fine 0.02–0.002	
Virgin sod:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	47. 24		1. 90	6. 75	7. 14	7. 33	24. 12	29. 65	11. 73	11. 38
2	51. 99	0. 09	2. 39	8. 24	9. 15	9. 24	22. 88	20. 96	16. 54	10. 51
3	53. 55	. 45	3. 32	9. 31	10. 18	9. 56	20. 73	27. 42	8. 62	10. 41
4	58. 78	. 20	4. 10	12. 11	12. 14	10. 81	19. 42	22. 46	8. 91	9. 85
5	60. 39	. 28	4. 00	12. 49	12. 30	11. 21	20. 11	22. 72	7. 15	9. 74
6	59. 01	. 37	3. 40	11. 60	12. 12	10. 95	20. 57	22. 60	8. 49	9. 90
7	58. 74	. 28	3. 32	11. 38	12. 19	10. 68	20. 89	23. 06	7. 86	10. 34
8	60. 36	. 14	3. 56	12. 40	13. 28	11. 86	19. 12	21. 13	8. 20	10. 31
9	59. 37	. 39	3. 34	11. 53	12. 03	11. 04	21. 04	23. 20	6. 66	10. 77
10	63. 90	. 22	4. 31	15. 48	14. 89	11. 91	17. 09	19. 41	6. 56	10. 13
11	63. 08	. 25	3. 45	13. 28	14. 22	11. 73	20. 15	20. 41	5. 71	10. 80
12	61. 95	. 32	3. 54	12. 39	13. 52	12. 26	19. 92	20. 77	6. 50	10. 78
13	63. 99	. 53	4. 66	14. 67	14. 46	11. 29	18. 38	19. 49	7. 63	8. 89
14	62. 31	. 31	3. 45	12. 83	13. 59	11. 77	20. 36	20. 18	6. 36	11. 15
15	62. 47	. 21	4. 37	13. 05	13. 67	11. 07	20. 10	20. 56	5. 67	11. 30
Plot A:										
1	76. 20	. 91	8. 78	18. 41	16. 91	15. 78	15. 41	17. 61	. 65	5. 54
2	78. 13	1. 14	10. 65	21. 13	17. 50	14. 28	13. 43	15. 99		5. 88
3	76. 64	. 77	9. 90	18. 05	16. 56	14. 56	16. 78	17. 58	. 36	5. 42
4	75. 25	. 70	8. 56	17. 55	15. 54	15. 45	17. 45	18. 52	. 77	5. 46
5	77. 08	. 67	9. 28	19. 58	17. 18	14. 98	15. 39	16. 74	1. 21	4. 97
6	78. 40	1. 63	11. 41	20. 25	16. 68	14. 34	14. 09	12. 75	3. 59	5. 26
7	78. 08	. 60	8. 45	19. 46	17. 96	16. 09	15. 52	15. 26	2. 79	3. 87
8	73. 77	. 88	9. 24	17. 84	17. 66	15. 12	13. 03	18. 07	1. 03	7. 13
9	66. 54	. 60	9. 32	17. 70	14. 26	11. 84	12. 82	19. 55	2. 59	11. 32
10	66. 63	1. 01	9. 37	17. 89	15. 39	10. 78	12. 19	18. 67	2. 91	11. 79
11	64. 70	. 88	7. 79	16. 19	13. 94	12: 46	13. 44	20. 86	2. 83	11. 61
12	69. 60	1. 66	9. 80	18. 30	15. 03	13. 03	11. 78	16. 71	2. 62	11. 07
13	71. 18	1. 53	10. 05	18. 71	15. 66	13. 24	11. 98	15. 82	2. 29	10. 71
14	70. 44	. 89	9. 28	18. 24	15. 67	13. 41	12. 95	15. 87	2. 86	10. 83
15	73. 43	1. 02	10. 50	20. 85	16. 58	13. 23	11. 25	16. 68		9. 89
Plot B:										
1	79. 29	2. 02	11. 46	19. 75	17. 27	14. 67	14. 12	8. 26	7. 19	5. 26
2	79. 87	1. 55	13. 21	21. 44	17. 17	14. 15	12. 35	13. 42	1. 78	4. 93
3	79. 89	1. 24	12. 05	20. 52	17. 74	15. 17	13. 17	12. 71	2. 59	4. 81
4	77. 05	1. 04	8. 84	18. 59	17. 18	16. 24	15. 16	16. 12	2. 50	4. 33
5	79. 70	1. 39	11. 44	21. 87	17. 12	15. 58	12. 30	12. 70	2. 91	4. 69
6	81. 36	2. 74	15. 88	22. 97	16. 78	12. 16	10. 83	11. 82	2. 50	4. 32
7	77. 67	1. 24	11. 08	21. 68	17. 20	14. 79	11. 68	13. 96	2. 99	5. 38
8	78. 31	1. 67	11. 29	21. 70	18. 10	14. 10	11. 45	13. 80	2. 67	5. 22
9	74. 23	1. 41	10. 17	19. 12	16. 43	13. 84	13. 26	15. 76	3. 73	6. 28
10	69. 35	1. 38	8. 83	16. 28	14. 19	12. 87	15. 80	19. 84	3. 21	7. 60
11	70. 86	1. 02	9. 41	18. 00	15. 73	13. 03	13. 67	17. 95	3. 95	7. 24
12	72. 24	1. 59	9. 57	18. 95	16. 21	13. 73	12. 19	14. 85	3. 35	9. 56
13	73. 80	2. 98	11. 55	18. 68	16. 15	12. 86	11. 58	13. 15	3. 43	9. 62
14	75. 74	1. 61	11. 26	21. 37	17. 56	14. 09	9. 85	12. 27	3. 06	8. 93
15	74. 86	1. 87	12. 23	21. 57	15. 79	12. 68	10. 72	12. 48	3. 14	9. 52

[1] Analysis by ARS—SWC Personnel in Stillwater, Okla., Laboratory.

[2] Size in mm.

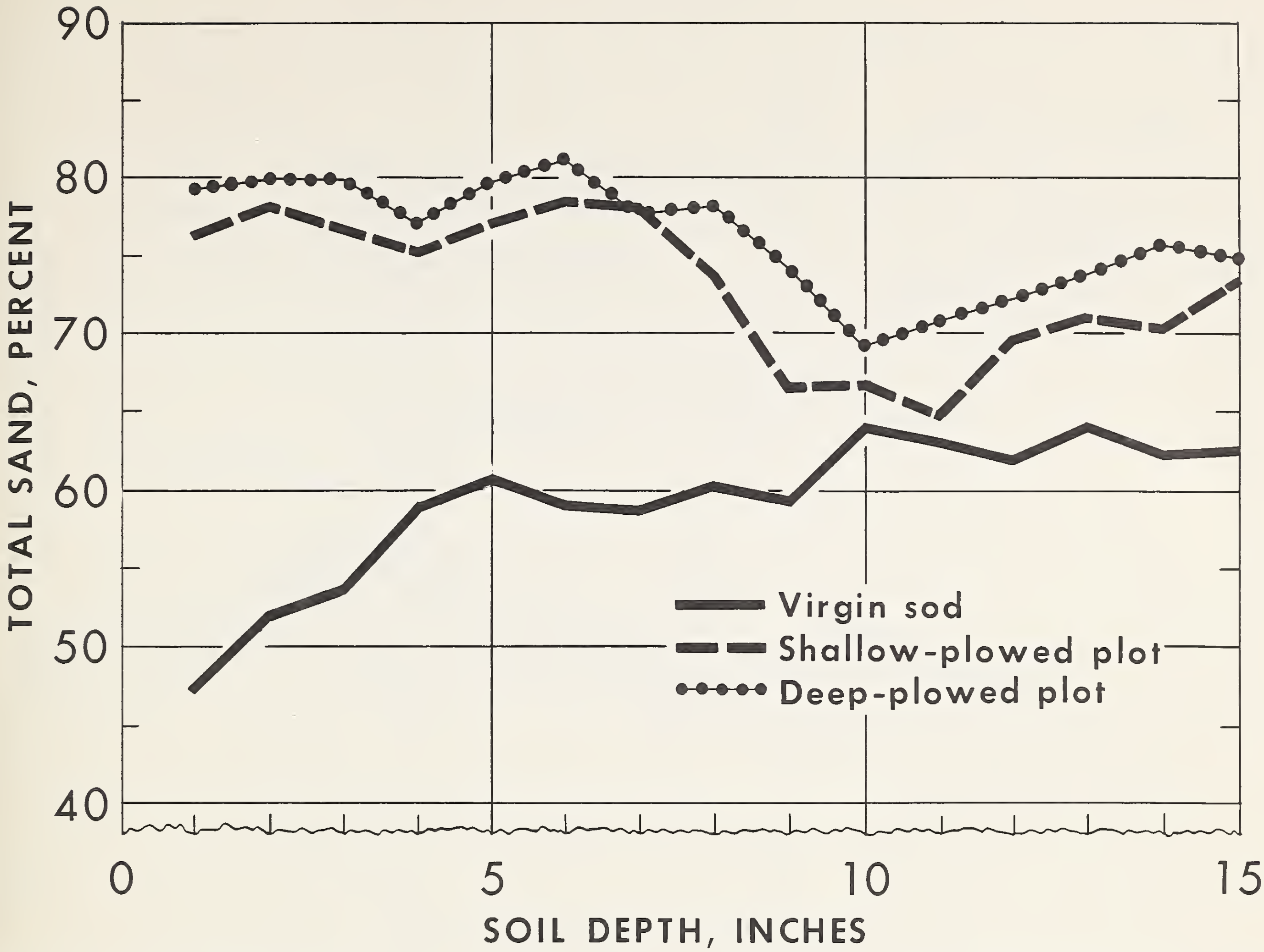

FIGURE 19.—Comparative total sand in soil from virgin sod; continuously cropped shallow-plowed Plot A and deep-plowed plot B. Woodward, Okla., 1956.

about the same as that in the undisturbed zones underneath.

The organic-matter data give a measure of the depletion of soil organic matter with cropping and of the effect of depth of plowing on depletion of organic matter. There is no evidence of a concentration or depletion of organic matter in the plowpan as compared with that in the soil above or below it. Depth of depletion appears to be a function of depth of plowing, even though it has taken place at greater depths.

The mechanical-analysis data indicate that the clay content is considerably lower in the plowed zone than in the plowpan and the soil below it. Comparisons with the virgin sod profiles indicate that the clay contents of the plowed zones have been depleted. It is not unreasonable to conclude that the clay was lost by wind erosion during 41 years of cultivation.

The data obtained in this study do not give evidence that the plowpan has been brought about by depletion or concentration of organic matter or of any particular-sized particles of soil in the compacted zones. These zones have formed below the depth of plowing.

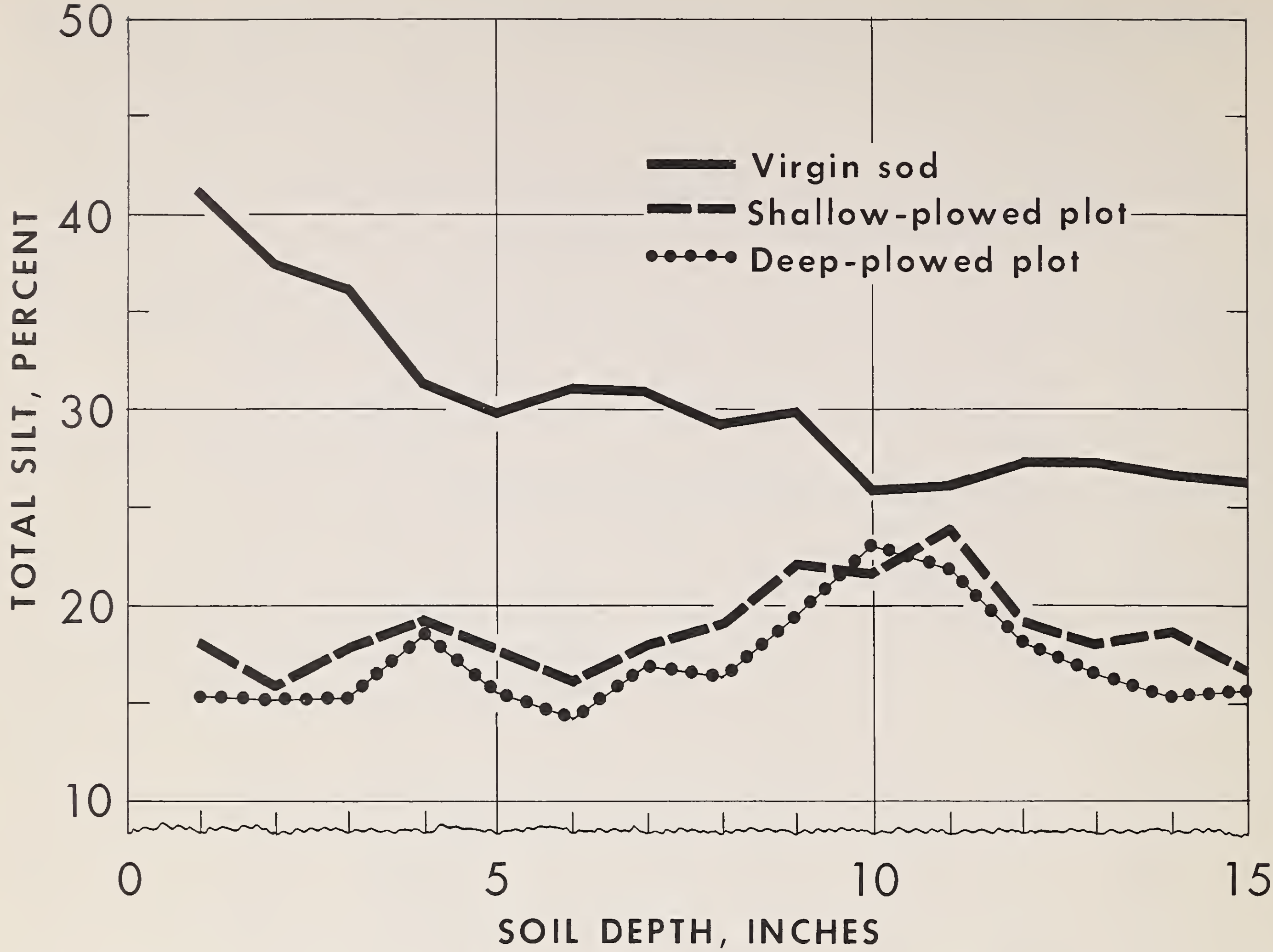

Figure 20.—Comparative total silt in soil from virgin sod; continuously cropped shallow-plowed plot A and deep-plowed plot B, Woodward, Okla., 1956.

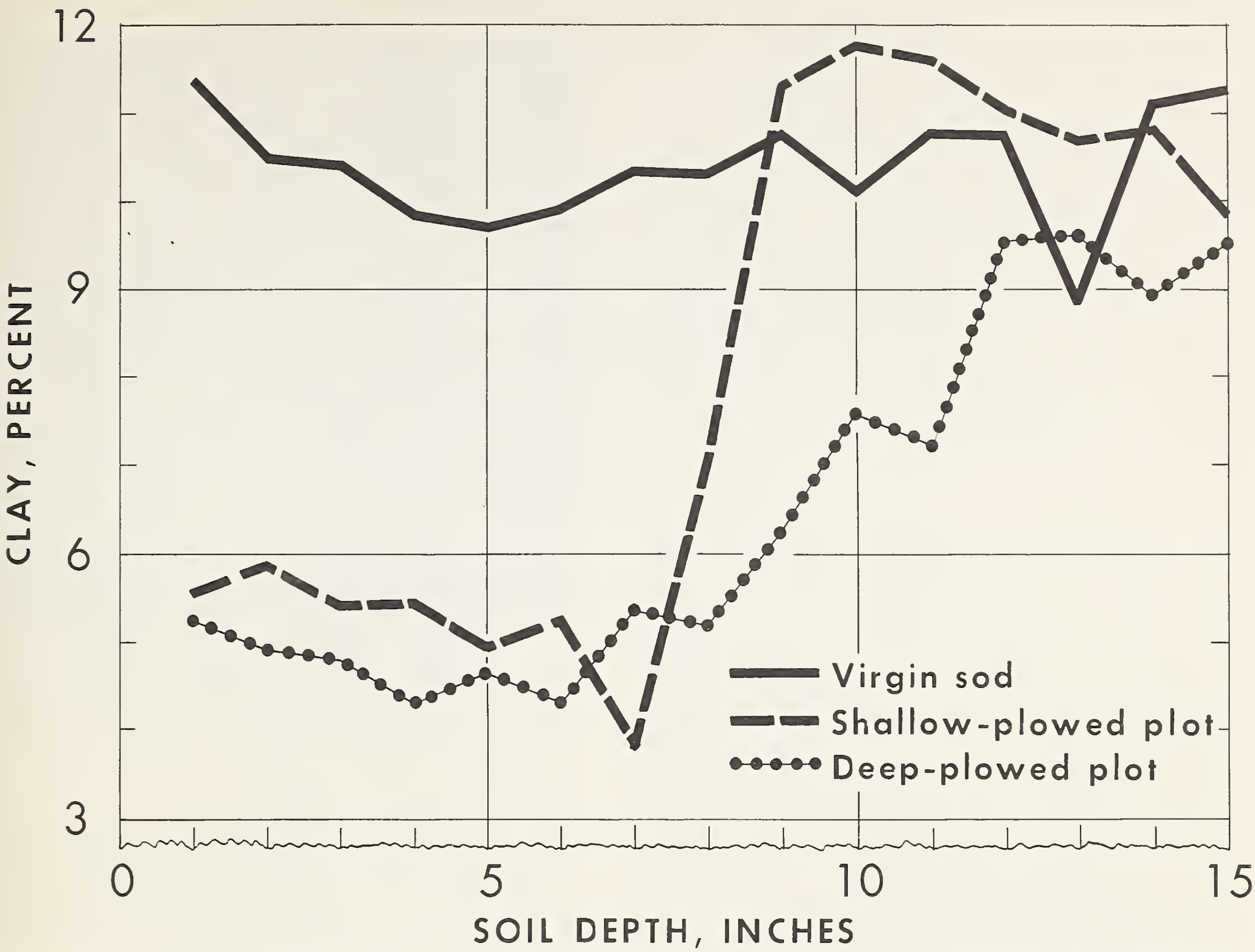

FIGURE 21.—Comparative clay content in soil from virgin sod, continuously cropped shallow-plowed plot A, and deep-plowed plot B. Woodward, Okla., 1956.

GREENHOUSE PLANT-GROWTH STUDIES

An exploratory experiment was conducted in the greenhouse to determine whether 6- by 17-inch sheet-metal cylinders (fig. 22) would be satisfactory for obtaining 15-inch cores of undisturbed soil. Construction of the cylinders was such that the side seams could be unbolted for easy removal of the cylinders (fig. 23), yet the cylinders would be waterproof when closed. Cores of soil were obtained by pressing the cylinders into the soil, removing the soil around the cylinders, and lifting the cylinders of undisturbed soil from the hole.

Cores were taken from the kafir shallow-plowed plot A. Soil in two of the cylinders was left undisturbed, and that in the other two was emptied, thoroughly mixed, and replaced in the cylinders. Two cylinders of soil, one undisturbed and one disturbed, were fertilized with N and P_2O_5 at the rate of 200 pounds per acre of each. The remaining two were not fertilized. Wheatland milo was planted in each cylinder on January 3, 1956, allowed to become well established, and thinned to two plants per cylinder on January 12. The plants were watered whenever watering appeared necessary. They were allowed to grow until March 21, when a series of photographs was made.

FIGURE 22.—Wheatland milo plants growing in 6-inch removable cylinders in soil: 1, Undisturbed and unfertilized; 2, undisturbed and fertilized; 3, mixed and unfertilized; and 4, mixed and fertilized.

Plants are shown in the removable cylinders in figure 22. In figure 23, plants and soil are shown after the cylinders were removed. The plant roots, with the soil washed from them, are shown in figure 24. The cylinders proved satisfactory for obtaining undisturbed soil cores and for use as pots. Plant roots grew through the undisturbed soil and did not concentrate at the soil-cylinder interface as it was supposed that they might. Plants grown in the fertilized soils (numbers 2 and 4) were darker green, had broader leaves, and were larger than those grown in the unfertilized soil (numbers 1 and 3). Depth of plowing can be observed in the undisturbed soils (numbers 1 and 2, fig. 23).

FIGURE 23.—Cylinders removed, showing soil differences and roots of Wheatland milo plants on surface of soil: 1, Undisturbed and unfertilized; 2, undisturbed and fertilized; 3, mixed and unfertilized; and 4, mixed and fertilized.

Both disturbance of the soil and fertilization affected root growth (fig. 24). Roots from the disturbed soils (numbers 3 and 4) grew deeper and were greater in volume; those from the undisturbed soils (numbers 1 and 2) were narrowed at the depth of the plowpan, as is particularly obvious in number 2. The fertilized soils produced a greater profusion of plant roots.

Another, more comprehensive, greenhouse experiment was conducted to determine the relative productivity of undisturbed cores of soil from

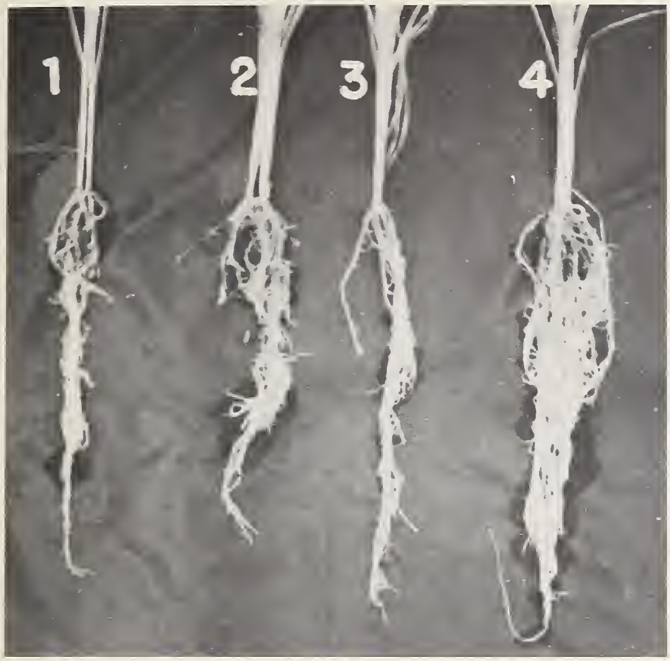

FIGURE 24.—Roots from Wheatland milo plants from soil: 1, Undisturbed and unfertilized; 2, undisturbed and fertilized; 3, mixed and unfertilized, and 4, mixed and fertilized.

various depths in cropped and virgin Pratt fine sandy loam. Soil cores were obtained from cultivated soil with a plowpan (kafir plot A) and from similar depths in virgin sod nearby. Cores were obtained from the following depths:

	Inches
Surface	1 to 4
Above pan	4 to 7
Split pan	6 to 9 [1]
Within pan	7 to 10

[1] Cores were not obtained from this depth on the virgin sod.

These cores were taken with a Uhland sampler and were kept in the 3- by 3-inch sampling rings throughout the experiment. Eight replicate cores were taken from each depth in both soils, making a total of 56 cores. The cores from each depth were divided into 2 sets of 4 replicates each. Each set of replicates was completely randomized and placed on blotter paper in plant flats. One set was initially saturated with a solution formulated by Hoagland (*4*) and the other with distilled water by submerging the bottoms of the cores (plant flats, blotter paper) and all in the desired solution in a shallow tank. Distilled water was used on both sets in later waterings.

The cores were allowed to drain to approximate field capacity, after which two Wheatland milo seeds were planted in each core. Care was taken to prevent undue disturbance of the soil. Upon seedling establishment, the stand was thinned to one plant per core. The plants were watered at weekly intervals with distilled water.

Seven weeks after planting, the plants were measured, representative plants were grouped by treatment and photographed, and all the plants were harvested and oven dried. Plant weight and height data are presented in tables 7 and 8. Average plants from each depth on both cropped and virgin soils are shown in figures 25, 26, 27, and 28.

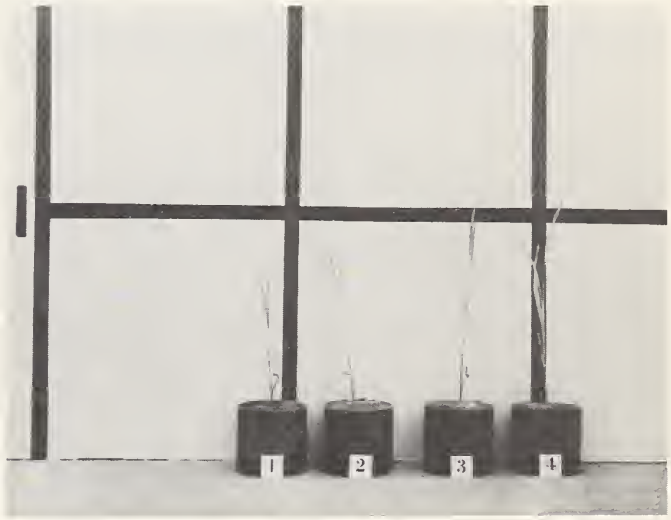

FIGURE 25.—Wheatland milo plants growing in cultivated, unfertilized soil from: 1, Surface, 1- to 4-inch depth; 2, split pan, 6- to 9-inch depth; 3, within pan, 7- to 10-inch depth; and 4, above pan, 4- to 7-inch depth. Woodward, Okla., 1956.

The virgin soil out-yielded the cropped soil at all depths, and the fertilized soils out-yielded the unfertilized soil from comparative depths (table 9). On the unfertilized cropped soil, the 4- to 7-inch depth gave the highest yield and the 1- to 4-inch depth the lowest yield. Yields from the other two depths were intermediate. When the cropped soil was fertilized, there were no appreciable differences in yield due to depth. On the unfertilized virgin soil, the 1- to 4-inch depth gave the highest yield and the 4- to 7-inch depth the lowest yield, whereas that of the 7- to 10-inch depth was intermediate. When the virgin soil was fertilized, the 1- to 4-inch depth still produced the highest yield and the 7- to 10-inch

Figure 26.—Wheatland milo plants growing in cultivated, fertilized soil from: 5, Surface, 1- to 4-inch depth; 6, split pan, 6- to 9-inch depth; 7, within pan, 7- to 10-inch depth; and 8, above pan, 4- to 7-inch depth. Woodward, Okla., 1956.

Figure 27.—Wheatland milo plants growing in unfertilized sod from: 9, 1- to 4-inch depth; 10, 4- to 7-inch depth; and 11, 7- to 10-inch depth. Woodward, Okla., 1956.

depth produced the lowest yield; that from the 4- to 7-inch depth was intermediate.

Table 9.—Weight of Wheatland milo plants grown in 3- by 3-inch unfertilized and fertilized cores of undisturbed soil from various depths of cropped and virgin soil. Woodward, Okla. Average of 4 replicates

Soil depth, inches	Unfertilized soil		Fertilized soil [1]	
	Cropped	Virgin	Cropped	Virgin
	Grams	*Grams*	*Grams*	*Grams*
1 to 4	0. 0546	0. 2233	0. 1611	0. 5299
4 to 7	. 1224	. 1293	. 1700	. 4572
6 to 9	. 0951		. 1647	
7 to 10	. 0892	. 1909	. 1713	. 2050

[1] Fertilized with Hoagland's solution.

It is not known whether sufficient fertilizer was applied in the Hoagland's solution to give maximum yields. If it is assumed that sufficient fertilizer was applied, the difference in the physical condition of the soil at various depths on the cropped soil did not influence yields. Also, the 1- to 4-inch depth of virgin soil was considerably more productive than the 7- to 10-inch depth, even when both contained sufficient fertility for maximum growth.

The wide difference in yield between fertilized cropped and fertilized virgin soils indicates that if sufficient plant nutrients were present to produce maximum yields on both soils, soil productivity has been seriously reduced by cropping and soil blowing.

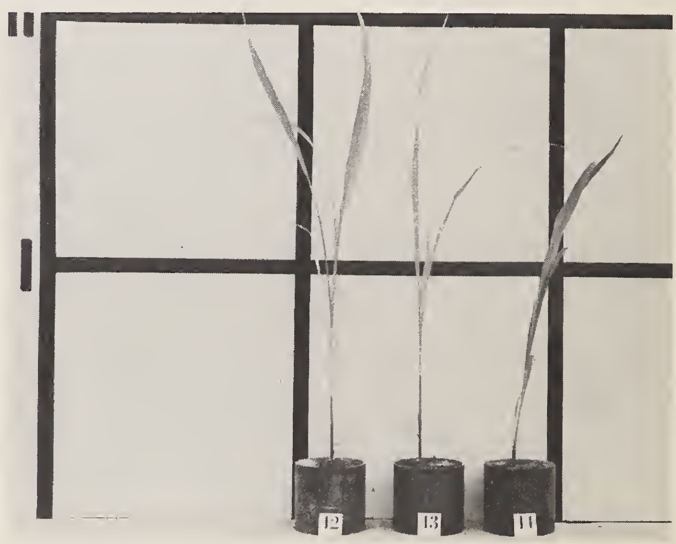

Figure 28.—Wheatland milo plants growing in fertilized sod from: 12, 1- to 4-inch depth; 13, 4- to 7-inch depth; and 14, 7- to 10-inch depth. Woodward, Okla., 1956.

SUMMARY

Pratt fine sandy loam at Woodward, Okla., and Cheyenne fine sandy loam at Mandan, N. Dak., were studied in attempts to characterize the physical nature of plowpans that had developed in both soils and to ascertain the effects of the plowpan on plant growth. Investigations were conducted in the field, laboratory, and greenhouse.

The plowpan found in the Pratt soil hinders root penetration, reduces infiltration of water, and increases soil erosion, and because of these effects, reduces crop yields. The plowpan found in the soil at Mandan is not sufficiently severe to influence crop yields.

In field and laboratory studies on the Pratt soil, infiltration was definitely reduced by the plowpan. Related laboratory measurements indicated that there were only minor differences in percolation rate, pore space, mechanical analysis, moisture equivalent, and bulk density, among the surface 3 inches of soil, a 3-inch layer of soil between the surface of the soil and the plowpan, and a 3-inch layer of soil including the plowpan. It was indicated that the clay content changed with depth and that the percolation rate was inversely related to the clay content.

In studies on the Cheyenne soil at Mandan significant correlation was found between penetrometer readings and soil-moisture determinations when the bulk density was greater than 1.30 grams per cubic centimeter. Penetrometer readings and bulk-density measurements were also found to be significantly correlated. It was concluded that bulk density had a greater influence on penetrometer readings than did soil moisture over the moisture range studied. The effect of a single plowing operation on soil compaction could be detected when soil moisture conditions were favorable for compaction. Freezing and thawing over winter did not reduce the compactness of the plowpan layer, and there was no change in this plowpan layer during the summer.

On the Pratt soil at Woodward, penetration, bulk-density, and soil-moisture studies on spring shallow-plowed, fall deep-plowed, and alternately cropped and fallowed plots of the old MC plots in field A, showed the following:

(1) The pressure required to penetrate the soil varied with the method of tillage as well as with the crop grown. The least pressure was required on the shallow-plowed soil; that required on the deep-plowed soil was intermediate, and that required on the alternate cropped and fallowed soil (deep fall plowed in crop years) was the greatest. Significantly less pressure was required to penetrate the soil on the milo plots than that on the corn, broomcorn, kafir, and sorgo plots.

(2) Bulk density of the soil varied with the method of tillage as well as with the crop grown. Bulk density of the spring shallow-plowed soil was least, that of the fall deep-plowed was intermediate, and that of the alternately cropped and fallowed soil was the greatest. Bulk density of the milo plots was significantly less than that of the corn, sorgo, broomcorn, and kafir plots.

(3) There was a significant correlation between bulk density and penetration pressure; however, the low coefficient of determination (0.22) indicated that the relationship was not of great predictive value. Further study indicated that changes in soil texture between plowed and undisturbed soil were responsible for the low correlation.

(4) A study of the correlation between soil-moisture content and penetration pressure indicated that variations in soil-moisture content did not affect penetration-pressure data in this study.

Organic-matter and mechanical-analysis data collected on soil from the fall deep-plowed soil, the spring shallow-plowed soil, and from a sod profile nearby indicated the following:

(1) That during 41 years of cropping approximately 50 percent of the original organic matter was lost on the shallow-plowed soil and 75 percent on the deep-plowed soil.

(2) Organic matter was depleted to a greater depth on the deep-plowed plots.

(3) Organic matter depletion took place below the depth of plowing on both plots.

(4) There was no evidence of a concentration or depletion of organic matter in the plowpan as compared with that in the soil above or below it.

(5) The soil below the depth of plowing on the shallow-plowed soil contained 114.8 percent more clay than that in the plowed layer; the comparable figure on the deep-plowed soil is 78.7 percent.

(6) There did not appear to be a concentration of any particular-sized particles of soil in the plowpan. The particle size distribution in the plowpan was the same as that in the undisturbed soil beneath it.

(7) Comparisons with the virgin sod profile indicated that the clay contents of the plowed zones had been depleted. It is not unreasonable to conclude that the clay was lost by wind erosion during the 41 years of cultivation.

Specially constructed 6- by 17-inch sheet-metal cylinders were satisfactory for obtaining cores of undisturbed soil and for use as pots for growing plants in the undisturbed soil.

Relative productivity of virgin sod and cropped soil was studied in a greenhouse experiment. Assuming that the fertilizer applied was sufficient to produce maximum growth on all soils, it may be concluded that:

(1) Differences in soil physical condition with depth to a depth of 10 inches on the cropped soil did not influence yields.

(2) The 1- to 4-inch depth of virgin soil was considerably more productive than the 7- to 10-inch depth even when both contained adequate fertility for maximum growth.

(3) Soil productivity has been seriously reduced by cropping and soil blowing.

LITERATURE CITED

(1) Bouyoucos, G. J.
1937. A SENSITIVE HYDROMETER FOR DETERMINING SMALL AMOUNTS OF CLAY OR COLLOIDS IN SOILS. Soil Sci. 44: 245–247.

(2) Briggs, L. J., and McLane, J. W.
1907. THE MOISTURE EQUIVALENTS OF SOILS. U.S. Dept. Agr. Bur. Soils Bul. 45, 23 pp.

(3) Duncan, D. B.
1955. THE NEW MULTIPLE RANGE TEST. Biometrics 11: 1.

(4) Hoagland, D. R., and Arnon, D. I.
1938. THE WATER-CULTURE METHOD FOR GROWING PLANTS WITHOUT SOIL. Calif. Agr. Expt. Sta. Cir. 347, 39 pp.

(5) Jamison, V. C., and Weaver, H. A.
1952. THE RELATIONSHIP OF MOISTURE AND MACROPOROSITY TO THE HARDNESS OF LLOYD CLAY. Agron. Jour. 44(6): 337.

(6) Kilmer, V. J., and Alexander, L. T.
1949. METHODS OF MAKING MECHANICAL ANALYSES OF SOILS. Soil Sci. 68: 15–24.

(7) Locke, L. F., and Mathews, O. R.
1955. CULTURAL PRACTICES FOR SORGHUMS AND MISCELLANEOUS FIELD CROPS. U.S. Dept. Agr. Cir. 959, 63 pp.

(8) Shaw, B. T., Haise, H. R., and Farnsworth, R. B.
1942. FOUR YEARS' EXPERIENCE WITH A SOIL PENETROMETER. Soil Sci. Soc. Amer. Proc. 7: 48–55.

(9) Terry, C. W., and Wilson, H. M.
1953. THE SOIL PENETROMETER IN SOIL COMPACTION STUDIES. Agr. Engin. 34: 831–834.

(10) Walkley, A., and Black, I. A.
1934. AN EXAMINATION OF THE DEGTJAREFF METHOD FOR DETERMINING SOIL ORGANIC MATTER, AND A PROPOSED MODIFICATION OF THE CHROMIC ACID TITRATION METHOD. Soil. Sci. 37: 29–38.

APPENDIX I.—SOIL AT WOODWARD, OKLA.

Classified as Pratt Fine Sandy Loam

Location:	Kafir A plot, U.S. Southern Great Plains Field Station, Woodward, Okla.
Classification:	Reddish Chestnut, Zonal.
Vegetation:	Sorghum since 1914.
Parent Material:	Aeolian.
Physiography:	Upland plain.
Relief:	Nearly level.
Slope:	Less than 1 percent.
Erosion:	Slight.
Permeability:	Naturally moderately rapid, but slowed by plowpan.
Drainage:	Surface good, good below plowpan.

Profile Description:

A_{1p}	0 to 7″	Very dark grayish brown (10 YR 4/2 dry, 3/2 moist) fine sandy loam; weak granular, soft dry, not sticky; clear boundary.
A_1	7 to 12″	Very dark grayish brown (10 YR 4/2 dry, 3/2 moist) fine sandy loam, weak to moderate fine and medium granular; friable, gradual boundary.
B_2	12 to 32″	Dark brown (7.5 YR 4/2 dry, 3/2 moist) sandy clay loam, to heavy fine sandy loam, moderate medium and fine granular; friable slightly hard when dry, very slightly sticky when wet, clear to gradual boundary.

C	32 to 42″	Yellowish red (5 YR 6/6 dry, 5/6 moist) fine sandy loam to sandy clay loam; massive, hard when dry, slightly sticky when wet.

Not many roots evident outside row area.

This soil is mapped as Pratt fine sandy loam in Northwest Oklahoma. It is a little heavier in surface texture than the modal Pratt fine sandy loam soil.

Described by Joe Nichols, Soil Scientist, Soil Conservation Service, Woodward, Okla.

APPENDIX II.—SOIL AT MANDAN, N. DAK.

Classified as Cheyenne Fine Sandy Loam

Silty Substrata Phase

Location:	U.S. Northern Great Plains Field Station, Mandan, Morton County, N. Dak., T 139N, R 81W 165′ west and 1105′ north of south quarter corner section 33.
Classification:	Chestnut alluvial.
Vegetation:	Tame grass, crested wheatgrass.
Parent Material:	Old sandy alluvium.
Physiography:	High terrace.
Relief:	Nearly level.
Slope:	Less than 1 percent.
Erosion:	Slight.
Permeability:	Moderate.
Drainage:	Well drained, profile slightly moist.
Remarks:	First 3 feet of material appears to be Aeolian over terrace materials.

Profile Description:

A_{1P}	0 to 8″	Black (10 YR 2/1 moist) loam with a fine weak subangular blocky structure. It is noncalcareous, friable when moist, slightly sticky and slightly plastic when wet. Abrupt boundary to—
A_1	8 to 16″	Very dark brown (10 YR 2/2 moist) noncalcareous loam which has a coarse weak prismatic structure. It is friable when moist and slightly sticky and slightly plastic when wet. It grades clearly into—
B_2	14 to 30″	Very dark grayish brown (10 YR 3/2 moist) fine sandy loam which has a coarse weak prismatic structure. It is noncalcareous nonsticky and nonplastic when wet. There are some faint traces of clay coatings on the vertical surfaces of the peds in this horizon. It grades into—
B_3	30 to 36″	Dark grayish brown (10 YR 4/2 moist) fine sandy loam with a coarse weak prismatic structure. It is very friable, nonsticky and nonplastic and noncalcareous, clear boundary to—
C	36 to 46″	Dark gray brown (10 YR 4/2 moist) fine sandy loam which has a coarse weak prismatic structure. It is strongly calcareous, very friable and nonsticky and nonplastic. Abrupt boundary to—
D_1	46 to 52″	Dark grayish brown (2.5 YR 4/2 moist) gravelly sandy loam which is strongly calcareous. It is loose and nonsticky.
D_2	52 to 64″	Light brownish gray (2.5 Y 6/2 moist) silt loam with a medium-sized weak angular blocky structure. It is friable, slightly sticky and plastic, and is strongly calcareous with some of the lime segregated into a few nodules.

Described by Soil Conservation Service personnel.

U.S. GOVERNMENT PRINTING OFFICE: 1960 O—553258